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# A HANDBOOK OF PRECIOUS STONES

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To  
MY FATHER  
, IN HEAVEN





## FOREWORD

Rao Bahadur Dr. Narayana Iyer has asked me to be a curtain raiser and I am very glad to comply, both because his book is of interest to me and also because he is an old colleague of mine.

Dr. Iyer's interest in gem-stones was first aroused when he was deputed to carry out a geological survey of the Mogok Stone Tract of Upper Burma in 1932, an area well known for its rubies and other gem-stones. In this book, written in a popular way, and giving a description of the more important precious and semi-precious stones, the author has produced in convenient form a concise account of the subject that will prove of interest to many in India.

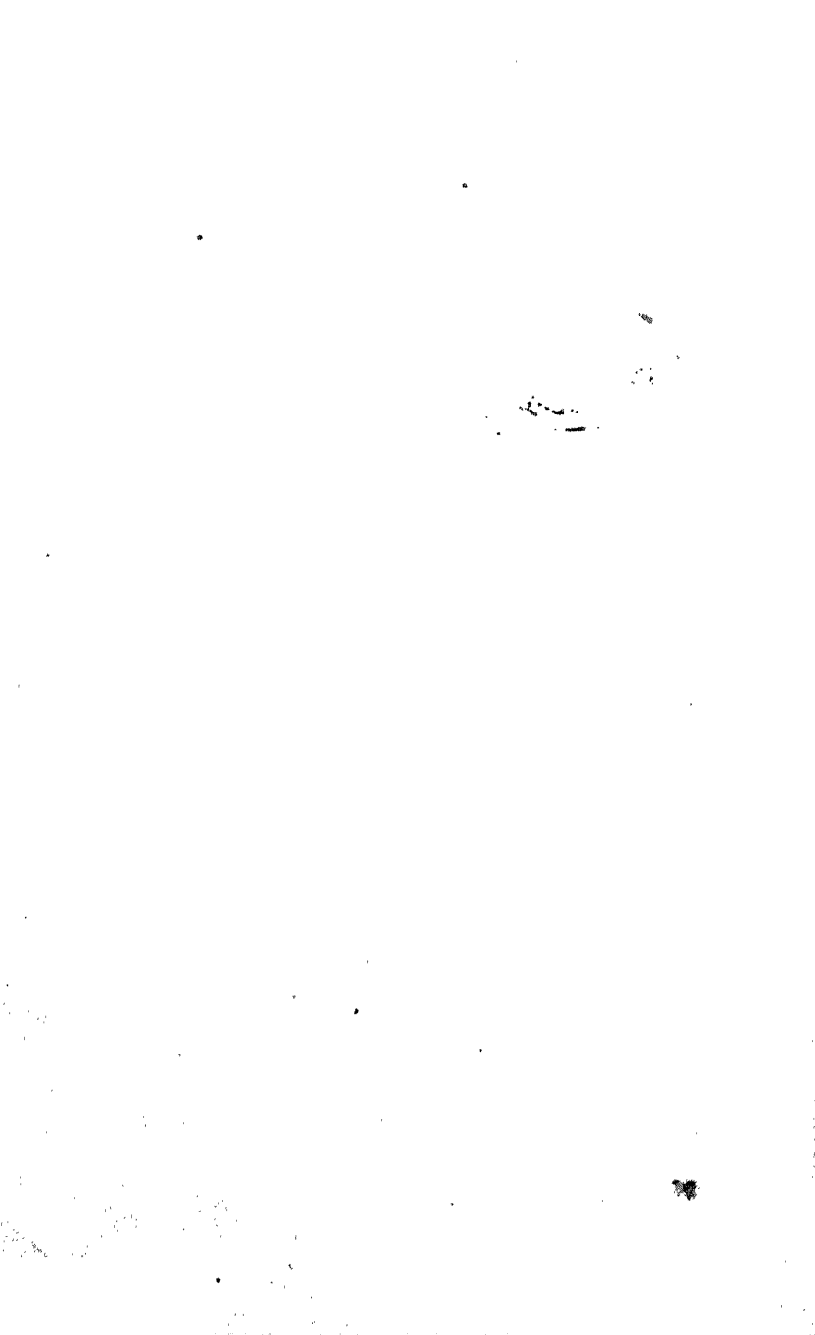
It is surprising how few gem-stones are found in India proper. Once the only known source of diamond, India produces now only a negligible quantity. The recent discovery of emerald in Rajputana, however, has aroused much interest; and as this stone is similar in physical and chemical properties to beryl, which occurs in abundance in that part of India, further finds may be expected.

At the present time the Indian market is flooded with imitation and synthetic gem-stones. The former can readily be distinguished from the natural stone; but the latter, in that the crystals synthesised have the same physical and chemical properties as the natural stone, require more erudition in their detection. Dr. Iyer discusses this aspect of the subject, and his discussion should prove useful to dealers in gem-stones who have some knowledge of the physical properties of crystals.

I recommend this book to all who are interested in gem-stones.

*Calcutta,*  
1-5-1947.

W. D. WEST.



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## PREFACE

Precious stones were known in India from very ancient times and references are to be found in ancient writings as the *Ramayana*, *Mahabharata*, etc., but their true nature, chemical composition and relationships were not well known. The only monumental work on Indian Precious stones is *Manimala* by Saurindranath Tagore, published in 1879-1881. Since then there has been no good Indian publication on the subject.

With the advance of the science of mineralogy in western countries, the study of precious stones, which are mineral products, also made rapid progress on mineralogical lines. Instead of the many popular names given to precious stones, it has been found that fewer mineralogical names should suffice. It has also been found possible to determine these correctly with some knowledge of mineralogy and the use of a few simple appliances.

The author's interest in gem-stones was aroused when he went to Mogok in connection with the geological survey of the Mogok Stone tract in 1932. Ruby mining in Mogok, besides producing rubies and sapphires, yields a number of miscellaneous gem-stones. The gem-vendors at Mogok always present to the newcomer sets of attractively arranged and coloured gem-stones. The geological survey of the Mogok Stone tract gave the author ample opportunities for familiarizing himself with most of the gem-stones.

After a more detailed study of gem-stones and their occurrences, the author contributed a bulletin on 'Indian Precious Stones' to the *Records, Geological Survey of India*, Vol. LXXVI, No. 6. This publication was soon

sold out. A reprint was then issued, which has also been sold out. In view of the great interest aroused on the subject of precious stones, it was suggested to the author to bring out a more detailed publication. The present book is to meet this demand. It is written in a non-technical style, and will, the author hopes, meet the demands of public interests on the subject of precious stones.

There are many scattered publications and some books on precious and semi-precious stones, which are given in the bibliography at the end of the book. The author has drawn information freely from most of them. Detailed references are omitted in the text, lest it might increase the volume of the book. The standard work is Max Bauer's *Edelsteinkunde*, translated by Dr. L. J. Spencer.

An attempt has been made to give in popular language a general and scientific account of the properties and composition of the precious stones, their occurrence, uses, etc., and also with special reference to India, wherever possible.

The author is deeply indebted for many useful suggestions and help that he has received from friends and colleagues. His sincere thanks are due to Dr. W. D. West, Director, Geological Survey of India, for very kindly contributing a Foreword and for much help.

In the preparation of the diagrams for crystals and instruments given in the book, much help was received from Babu Anil Mukerji, Artist's Section of the Geological Survey of India, to whom the author is very grateful.

The Baptist Mission Press, Calcutta, also deserve special thanks for their courtesy in undertaking and carrying out the work.

PATNA,  
14-2-1948.

L. A. N. IYER.

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## A HANDBOOK OF PRECIOUS STONES

## CHAPTER I

## INTRODUCTION

PRECIOUS stones have been known from ancient times. Early man appreciated the beautiful in nature, such as coloured berries, attractive shells, brightly coloured pebbles, etc., and used them for personal adornment. Countries in the eastern hemisphere were the first to use precious stones or gems, dating back to 100000-75000 B.C. There are many circumstances that point to India as their birthplace. Mention is made of gems and jewels in the earliest Hindu writings. The Vedas have references to places illuminated by rubies and diamonds. Precious stones play a very prominent part in Hindu mythology, in Hindu traditions, poems and legends. In their two great epics, the *Ramayana* and *Mahabharata*, kings and people are said to have decorated themselves with stones and pearls. The Phoenicians brought precious stones and jewels to Egypt and Greece from the East.

India and Burma formed the home of many gem-stones and there existed a trade between India and Europe on gem-stones. The emerald is said to be known from 2000-1800 B.C., sapphires and ruby from 600-500 B.C. and diamond from 480 B.C.

Gem mining is probably the oldest form of mining. Primitive man is said to have known 18 gems and decorative stones before he knew of any metals. At first the gems were sought in stream gravels and residual deposits, but by 3400 B.C. the turquoise mines of the Sinai Peninsula were operated. This was probably the first human



enterprise in the mining of hard rocks. The Lapis lazuli mines of Afghanistan might be equally old. The emerald mines of Egyptian Red Sea coast were operated about 1925 B.C. The diamond deposits of India and the sapphire-ruby mines of Ceylon were working about 800-600 B.C. Brazil came to prominence in diamond mining in 1725 A.D. which in turn was superseded by South Africa in 1870 A.D. The centre of the world's trade in gems as known to Europeans have been successively Babylon, Alexandria, Rome, Venice and Amsterdam; and now London, Paris, Antwerp, Amsterdam and New York. But the Second World War has caused wide-spread disturbance in Europe.

Precious stones form one of the most valuable and compact of commodities, which had an upward trend in value over long periods. Great wealth could be concentrated in a small packet of stones. Since they enjoy an international market, precious stones served as a form of investment for centuries. This has promoted in a reasonable growth of the family fortunes of some Hindus. The same tendency prevailed also in the West where wealth is easily hidden or easily transported in the event of any disturbance to political tranquillity. During the recent war there has been a great tendency to invest in precious stones, and the gem trade is having a prosperous time. Precious stones have also promoted exploration and the travels of gem merchants formed a useful source of information regarding the East to Europe in the middle ages.

Precious stones are regarded as 'flowers of the Mineral Kingdom'. They are minerals with a few exceptions such as pearls, corals and ivory which are animal products; amber and jet are of vegetable origin. The gem materials or precious stones are minerals distinguished by their hardness, which enables them to be worn as personal ornaments without deterioration, and by their colour and lustre which render them attractive. These qualities might be had in several minerals, some of which could not

be called 'precious', but may be called 'semi-precious'. Precious stones are those that are really rare and hard to get.

This is only an arbitrary definition. Ruby and emerald are now rare and difficult to obtain and hence regarded as precious stones of first rank. But if any large deposits of these were to be discovered and if amethyst were to become rare, then amethyst would come into great favour thus causing an interchange of rank. Again this argument is defied by diamond. Large deposits of diamond have been discovered in recent years. But the market is controlled by a powerful combination; large stocks are held in reserve, and its rank as a precious stone with its high price is maintained and aided, of course, by its intrinsic properties.

### SYNTHETIC GEMS

This subject is treated in a subsequent chapter. Corundum of gem quality with a wide range of colours has been manufactured artificially in large quantities during the last 40 years. The gem trade had a very severe competition from this source and the ruby mines of Burma experienced a severe setback. Their Madras business collapsed. The new stones were very popular with the poorer classes of people but the natural stones always found favour with the middle and richer classes.

There are 1,200 mineral species so far known and about 50 of them have been cut and polished as gem-stones. The rarer gems are treated as precious stones, and the more common ones as 'semi-precious stones'. There is no law regarding prices. Common rough corundum may cost only Rs.15 per ton, but stones of the gem quality sell by the carat, which may cost £100 or even £1,000 for the best quality.

*Qualifications of Gem-stones.*—A mineral has to satisfy the following conditions to be qualified as a gem-stone. A gem-stone may not possess all the qualities that are

mentioned below, but the diamond satisfies all the conditions and is highly esteemed as a gem.

(i) The splendour or beauty of a stone depends on its *colour, lustre, play of colours* and *brilliancy* or *fire*. These properties are discussed in detail in a separate chapter. A coloured diamond has all these properties, but it is very rare. Rubies and emeralds have beautiful colours but they lack brilliancy and fire. Opal is attractive only due to its play of colours. The rough stones are often dull pebbles, but cutting and polishing improve their properties. Hard stones take a better polish than the soft ones.

(ii) *Durability*.—Precious stones should be at least harder than dust particles in the air. So they must be harder than quartz, or they are easily scratched and wear out quickly. Diamond, ruby, emerald and sapphire are harder than quartz.

(iii) *Rarity*.—This is a valuable attribute to gems and has been discussed already.

(iv) *Fashion*.—Fashion plays a great part in the value of gems. A gem may be very popular at some period and fall into desuetude at another period. Some colours are always liked, e.g. blue, red and green, whereas yellow is not much liked. Ruby, sapphire and emerald have been very popular in South India, but diamond has now become the fashion with the middle and richer classes. Certain stones attain local popularity due to their production and easy availability there.

## MINERALOGY AND GEMS

Gems are mostly mineral species. Methods applicable to the study of minerals could be applied to identify gemstones, and are dealt with in Text-books of Mineralogy and Treatises on Gem-stones. The most valuable publication in this line is Max Bauer's *Edelsteinkunde*, which was translated by L. J. Spencer in 1904. There is a recent

edition of the same in 4 volumes in German. Other useful manuals are: (1) *A Key to Precious Stones* by L. J. Spencer; (2) *Gems and Gem Materials* by Krauss and Slawson; (3) *Gem-stones* by H. G. Smith. *The Journal of the Gemmological Society of London* is a useful one which contains valuable contributions. But there are not many recent publications on Indian gem-stones. But it may be mentioned that one of the most valuable Indian publications is *Mani-Mala*, a treatise on gems by Raja Sourindra Mohun Tagore, published in 1881, which contains a wealth of information on precious stones. But the book is out of print and not available to many. All these books are of great use to students of gemmology.

## GEMMOLOGY

That part of mineralogy which is specially useful for the study of gems is now being called 'Gemmology' in western countries. People specialize in gemmology and there is a journal of gemmology in England and America. Some knowledge of Mineralogy and Chemistry are also helpful to understand the technique of the manufacture of synthetic gems.

The first nine chapters of this book deal with the elementary facts of Mineralogy requisite and provide a scientific background for a detailed study of the gem materials.

## CHAPTER II

### HOW GEM-STONES OCCUR AND HOW THEY ARE WON

GEM-STONES have been found in the oldest of geological formations known as the Archaeans—formed long before the advent of life and perhaps dating back to a thousand million years. But it does not follow that they occur always in the Archaeans and everywhere in them. Gem-stones

also occur in rocks of other geological ages; perhaps they are even now being formed in the earth's interior. Another interesting period is the Cretaceous, i.e. a period only about 60 million years ago. In the Cretaceous of Australia occur opals while in Colombia emeralds occur in limestone. During this age the diamond pipes of South Africa were also formed.

## ROCKS FORMING THE EARTH'S CRUST

Rocks forming the earth's crust are grouped into three main divisions: (a) igneous, (b) sedimentary, and (c) metamorphic according to their origin, without reference to their geological age and representatives of each class may occur in all geological ages and formations.

(a) *Igneous rocks*.—These consist of silicate minerals crystallized from a molten magma. They are of diverse kinds, varying in chemical composition, mineral composition, structure and texture. The igneous rocks are either extrusive or volcanic or intrusive or plutonic. The volcanic rocks have cooled quickly under atmospheric pressure and may even be glassy like obsidian or partly crystalline like basalt. Small crystals of hauyne, sapphire or red zircon may occur in them. The igneous rocks have cooled slowly under great pressure deep below the crust. They are coarsely crystalline and their mineral constituents could be easily identified. The following igneous rocks may contain some gem minerals:—

(a) granite may contain good crystals of beryl, topaz,  
zircon, etc.

(b) Syenite                   ,,                   ,, corundum (ruby and  
sapphire)                   and  
zircon.

(c) Peridotite               ,,               ,, corundum.

These minerals are primary, but as they are present only in very small amounts they are termed accessory minerals;

but corundum may occur in great amount in corundum syenites. Although large bodies of igneous rocks are exposed on the earth's crust in several parts of the world, most of them do not contain any precious stones. But in the final consolidation of these large bodies of igneous rocks, the residual fraction or mother liquor, consisting of liquids and volatiles, are kept under great pressure and moderate temperatures. When the pressure could overcome the country rocks, these liquids are injected through fissures and cracks, which on cooling form coarsely crystalline rocks known as pegmatite, which forms sheets, lenses, veins and dykes. Many gem minerals occur in pegmatite dykes with other less valuable minerals, since materials for forming a number of minerals and gems are contained in this mother liquor. Steam cavities also occur in pegmatite dykes, where crystals could grow to great size, e.g. beryl, topaz, quartz, tourmaline, amazon-stone, etc. Such crystals can be broken away from the wall of the cavity. The embedded crystals may also attain enormous dimensions—feldspar crystals weighing 200 tons were found in Norway as also a spodumene crystal weighing 90 tons in South Dakota. These pegmatite veins finally grade into vein quartz, which might also carry some gold and gem minerals.

These igneous bodies are originally formed at depth but after some ages become exposed at the surface, when the gem-stones become accessible to man. Nature lends a great helping hand in this by the processes of denudation, which wear away large thicknesses of rocks through the agency of rain, frost, ice, changes of temperature, wind, waves, etc. Gem minerals may occur in the material thus broken down, either exposed or carried away.

(b) *Sedimentary rocks.* The material worn out by denudation is transported and deposited in water forming the sedimentary rocks, e.g. clay, shales, sandstone, limestone, chalk, etc. A few of them might contain some

gem material formed contemporaneously with the original rocks; sedimentary rocks in some areas also contain gem minerals of detrital origin. Such rocks when crushed, powdered and separated, yield small quantities of gem material. The diamonds of India and Brazil and some portions of Africa are detrital and occur in sedimentary rocks of pre-Cambrian age. But diamond-bearing conglomerates of Triassic age are also found in the Belgian Congo and Angola.

(c) *Metamorphic rocks*.—Sedimentary or igneous rocks, when buried deep in the earth, are generally subjected to great pressure and heat. They are exposed later by denudation by the removal of the cover. In some of them gem minerals have been found, e.g. corundum and garnets which have high density, with other minerals such as kyanite, staurolite and beryl. Ground water when circulating through cracks and crevices may cause secondary changes to take place yielding a few new minerals, which may have had their origin in the country rock, or from outside or by interaction of two sets of materials. A few minerals are formed in this way, e.g. agate, amethyst, Hungarian opal, Persian turquois. There are also secondary minerals in rocks of Tertiary age.

It has been found that the same mineral may be formed in nature by more ways than one. Corundum and beryl may be of igneous or metamorphic origin, emerald in limestone or secondary origin. Quartz and its varieties are formed under varying conditions. Though gem-stones have been mentioned as occurring in rocks of all ages, it is important to note that their occurrence is exceptional. Even if the stones are found sparingly in the rock, it may not pay to break the rock for the gem-stones. Nature, as already referred to, has in many cases done this work for man by steady work through countless ages by the processes of denudation. The material broken up is carried by running water and sorted on the way—lighter

materials travelling far, and heavier material being left behind in pockets or holes and covered up by mud, sand or gravel. Most gem-stones occur in such alluvial deposits, their occurrence being governed by the presence of gem-bearing rocks in the neighbourhood.

The gem-stones recovered from gravels are worn to some extent—the edges are rounded, faces dulled and the crystals changed to rounded pebbles. Flaws and cracked portions may be removed during the process thus yielding the best gem material, as in the case of the diamonds of India and the rubies and sapphires of Burma and Ceylon. The gravels are panned for gold, which lead to the discoveries of gem minerals. These rounded pebbles of gem minerals are generally not easy to recognize without some knowledge of gemmology.

Most of the valuable gems occur in alluvial deposits in deep valleys of mountainous countries. Mining is usually carried on by people in small groups according to primitive methods. A prospecting pan often serves their purpose. These gem washers have great skill in washing the gravel and separating gem-stones. But the more advanced methods of the present day consist in the use of a jig or jigger, which is also used to separate metallic ores from their gangue. In large plants, as in the Kimberley diamond mines, the material is passed to the jigs, after washing in circular pans. These methods require a large amount of water. In dry areas, where water is scarce, winnowing or blowing by the wind is practised. This carries away the dust and lighter material and the rest is hand-sorted.

Workings in alluvial deposits are small, but the Burma Ruby Mines Co. used more efficient methods, and systematically dealt with large amounts of material. The Burmese wash down the material on the hillside with a powerful jet of water or hydraulic mining (hydraulicking). In the Vaal river in Africa, the whole gravel is excavated from the river bed after diverting its course.



Gem mining in solid rock is exceptional. Diamond mining of South Africa is an example. Pegmatite veins often contain gem minerals, and they have been worked for quartz, topaz and tourmaline in Burma and for tourmaline and beryl in Brazil and South-West Africa. At times these pegmatites are weathered to a soft material, which is easily worked, e.g. the sapphire-bearing pegmatites of Kashmir. The emerald mines of Colombia are open quarries in limestone.

The only instance, where gem mining is done by modern methods using large scale mechanical aids is provided by the diamond mines of South Africa. The 'Premier' mine near Pretoria is the largest open quarry on earth. The Kimberley mines were worked as open quarries to a depth of about 1,300 ft. after which underground mining had to be resorted to as in the case of coal or metal mines. The rock is broken up, carried to the surface, then crushed, washed, jigged and dealt with just like an ordinary ore. The 'Blue ground' forms the diamond ore. In South-West Africa, the diamond is found in a sand dune along the coast. The dunes are attacked with mechanical excavators mounted on caterpillar trucks driven by electricity. They pick up 5-10 tons of material at each scoop. The material is carried to the works where it is sieved, panned or jigged. The final concentrate contains small diamonds.

### CHAPTER III

#### CHEMICAL COMPOSITION OF GEM-STONES

GEM-STONES are well known from ancient times but a knowledge of chemistry is of modern growth. For this reason gem-stones are more known by their ancient names than by their composition. Chemists know of 92 elements, which may occur in nature singly or combined. Aluminium and oxygen are elements which when combined form

alumina and this compound in its crystallized condition is known as corundum. Only a few common elements go to form gem-stones. Diamond is the only gem-stone made up of a single element. All the others are chemical compounds mostly containing oxygen, except one which is a compound of fluorine. The elements that are common in gem-stones are silicon, aluminium, iron and magnesia. Besides, other elements may occur in traces or in small amounts.

The elements can be represented by their chemical symbols and atomic weights and their combinations by chemical formula. Two atoms of aluminium and three atoms of oxygen go to form alumina (corundum or ruby) which is written down as  $\text{Al}_2\text{O}_3$  (a molecule).

For a scientific classification of gem-stones, a knowledge of the chemical composition is essential. Equally essential is the crystalline structure. All other characters depend on them. Chemical tests are not very useful for gem-stones as they will require the destruction of the stones. Hence for purposes of determination, physical tests which do not harm the stones are the most important.

#### CHEMICAL CLASSIFICATION AND FORMULAE OF CHIEF GEM-STONES

##### *Elements*

Diamond	C
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##### *Haloids*

Fluorite	CaF <sub>2</sub>	<i>Aluminates</i>
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##### *Oxides and Hydroxides*

Quartz	SiO <sub>2</sub>	Spinel	MgO . Al <sub>2</sub> O <sub>3</sub>
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Corundum	Al <sub>2</sub> O <sub>3</sub>	Chrysoberyl	BeO . Al <sub>2</sub> O <sub>3</sub>
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Rutile	TiO <sub>2</sub>	<i>Carbonates</i>	
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		Pearl	CaCO <sub>3</sub>
--	--	-------	-------------------

		Coral	CaCO <sub>3</sub>
--	--	-------	-------------------

Cassiterite	SnO <sub>2</sub>		
-------------	------------------	--	--

Hematite	Fe <sub>2</sub> O <sub>3</sub>		
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Opal	SiO <sub>2</sub> xH <sub>2</sub> O		
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### *Phosphates*

Turquoise  $\text{H}_{18}\text{CuAl}_6\text{P}_4\text{O}_{29}$

Apatite  $\text{Ca}_5\text{FP}_3\text{O}_{12}$

### *Silicates*

Beryl (emerald)  $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$

Orthoclase (moonstone)  $\text{KAlSi}_3\text{O}_8$

Garnet  $\text{M}_3\text{M}_2(\text{SiO}_4)_3$

## CHAPTER IV

### FORMS OF CRYSTALS

IT has been mentioned that gem-stones are minerals. A mineral is defined as a substance occurring in nature with a characteristic chemical composition, and usually possessing a definite crystalline structure. When crystalline it has also external geometrical forms or outlines. Definite crystalline structure means that the structural units of a mineral, i.e. groups of matter have a definite and an orderly arrangement, which is characteristic of each particular mineral. Most gem minerals exhibit external geometrical forms or outlines. These forms are known as crystals. The diamond, ruby and sapphire and emerald occur as crystals.

Crystal structure and X-rays has been a subject of special study which is not included in our study of gem-stones. Each kind of gem-stone has its characteristic crystalline form and may occur in well-formed crystals. If one looks at the crystalline faces, one can often say at a glance to which mineral the crystal belongs. Even water worn crystals could be identified by their general shape. Thus an elementary study of crystallography is of value to the student of gemmology, who will find it helpful to identify easily uncut material. Moreover, a knowledge of the crystallographic properties is essential for the efficient cutting of gems.

## CONSTANCY OF CRYSTAL ANGLES

The angles between similar faces remain constant regardless of the size or the shape of the crystal for the same substance. This is a very important property of crystals, whereas sizes and shapes of faces may be distorted by irregular growth. There are instruments known as goniometers for correct measurements of crystal angles.

## SIZE OF CRYSTALS

Crystals exhibit variations from microscopic dimensions to those weighing several tons. Large crystals of spodumene and beryl have been found to weigh several tons.

## CRYSTAL SYSTEMS

All crystals fall into six groups according to the length and inclination of imaginary lines known as the crystallographic axes which are fundamental to their structure.

1. *The cubic system.*—Crystals of the cubic system have three mutually perpendicular and equal axes. The forms known as cube, octahedron, dodecahedron and tetrahedron belong to this system. Diamond, spinel, and garnet are examples of this system. The cubic system has the highest symmetry, e.g. it has three cubic planes of symmetry, six other planes of symmetry and has 13 axes of symmetry.

2. *The tetragonal system.*—In this system, crystals have three axes which intersect at right angles, but the vertical axis is longer or shorter than the horizontal axes. Zircon and Vesuvianite occur in this system. This system is characterized by five planes of symmetry, one tetrad axis of symmetry, six dyad axes of symmetry and a centre of symmetry.

3. *The hexagonal system.*—Hexagonal crystals have four axes—three are horizontal and equal, and intersect at  $60^\circ$ . The fourth is longer or shorter than the horizontal

ones and is the hexad axis at right angles to them. It has seven planes of symmetry, a single hexad axis of symmetry, six dyad axes of symmetry, and a centre of symmetry. Beryl, emerald, ruby and sapphire, quartz and tourmaline crystallize in this system.

4. *The orthorhombic system.*—This system has crystals with three unequal axes but all of them are perpendicular to one another. It has three planes of symmetry, three dyad axes of symmetry and a centre of symmetry. Topaz and olivine crystallize in this system.

5. *Monoclinic system.*—There are three unequal axes of which two intersect at an oblique angle, while the third is perpendicular to them. It has one plane of symmetry, one dyad axis of symmetry, and a centre of symmetry.

6. *The triclinic system.*—In this system, the three axes are unequal and all are inclined. It has only a centre of symmetry, e.g. labradorite and moonstone.

The symmetry gradually diminishes with each system in the order given above and each system has also several classes in which the symmetry is only partial, i.e. only one-half or one-fourth of the full number of faces is developed. These are known as hemihedral and tetartohedral forms as distinct from the holohedral or full faced forms. There are 32 of these crystal classes and only a few of them include gem-stones.

The morphological classification of crystals into systems is not at all artificial. Optical properties form also a second natural basis for classification, which divide the crystals into three groups: (1) cubic, (2) tetragonal and hexagonal, and (3) orthorhombic, monoclinic and triclinic. These are dealt with in detail in a later chapter.

## CRYSTAL FORMS

1. *Cubic system.*—The common forms are the cube which has six square faces and is similar to the geometrical cube; the octahedron has eight triangular faces, the

dodecahedron has twelve diamond shaped or rhombic faces. Other forms are the tetrahedron with only four triangular faces. These forms may occur together in a crystal, which is then known as a combination of forms. (See figs. 1-5).

2. *Tetragonal system*.—Tetragonal prisms have four or eight faces and are parallel to the vertical axis. Tetragonal pyramids have eight or sixteen faces. Basal pinacoids are the top and bottom faces. Combinations of the above forms are seen in zircon. (See figs. 6-9).

3. *Hexagonal system*.—The forms in this system have faces in numbers which are in multiples of six. The hexagonal prism has six or twelve faces arranged parallel to the vertical axis. Other forms must be present in combination with a prism. So a prism is known as an open form. Hexagonal bipyramids represent a form with two pyramids placed base to base. The forms may have twelve or twenty-four faces. These are closed forms. The *Basal pinacoid* has two parallel faces at right angles to the vertical axis. The top and bottom faces of prisms are pinacoids. The *Rhombohedron* has six rhombic or diamond shaped faces. The *Scalenohedron* has twelve faces which are scalene triangles and hence the name. Combinations of prisms, bipyramids and basal pinacoids are common as in beryl; combinations of prism and rhombohedron are common in quartz. (See figs. 10-18).

*Orthorhombic, monoclinic and triclinic systems*.—These three systems have their forms so much alike and are considered together. *Prisms*: Forms parallel to the vertical axis, but intersect the lateral axis; *domes* similar to prisms, but are parallel to a horizontal axis. *Bipyramids* are similar to those already dealt with. *Pinacoids*: There may be three kinds of pinacoids, each consisting of two parallel faces. Each face cuts one of the axes and is parallel to the other two. (See figs. 19-23).

In the triclinic system forms can have only two similar or parallel faces. The different faces in crystals are

distinguished by indices, which are given by the relative lengths the faces intercept on the axes of reference or one or two faces may be parallel to a face.

*Compound crystals.*—Crystals may be single or individual or may be of several individuals, i.e. compound crystals: (i) parallel groups, (ii) twin crystals. In (i) the crystal axes are parallel. In (ii) the crystals have intergrown in a special manner. A twin may also consist of more than two individuals—they may be of the contact type or the penetration type.

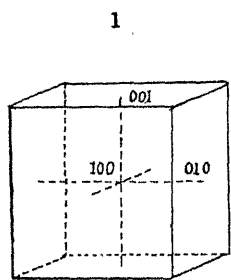
## CHAPTER V

### COLOUR, LUSTRE, BEAUTY, ETC.

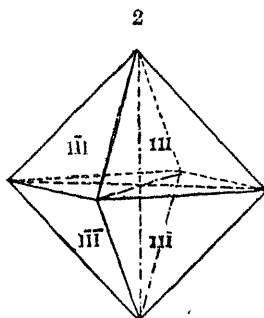
GEM-STONES are made very attractive by their colours, and some have to depend solely on their colour for their charm and appeal. Colour is also influenced by the light used and on the degree of colour vision of the observer. Colours are seen well in white light. The colour of gem-stones in most cases is accidental and not essential. Most gem-stones in a pure state are without colour. The colouring matter may consist of various metallic oxides in quite small amounts. Wonderful colour effects have been produced in synthetic stones by the addition of metallic oxides. There is also a theory that coloured crystals contain colloidal particles, either of foreign matter or of the crystal itself and that the colour seen depends on the size of these particles.

At times the colour may be unevenly distributed and may occur as irregular patches or blotches as is often the case with amethyst and sapphire. The colour may also be distributed in regular bands or zones. The variety of quartz known as agate shows banding with different colours. Inclusions may also produce colours, as in moss agate.

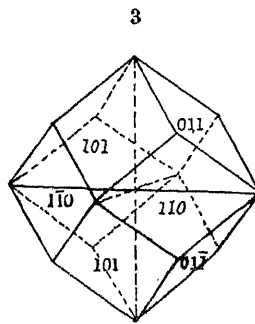
In some gem-stones the colours disappear on heating and could be restored by exposure to radium. Some gem-stones



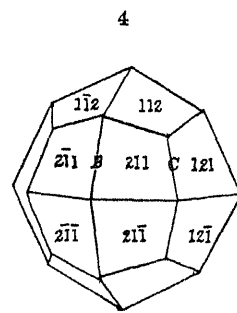
Cube



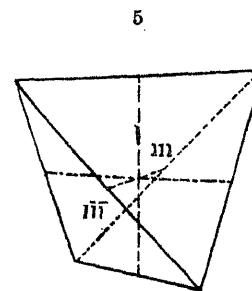
Octahedron



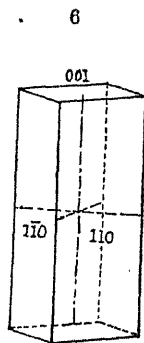
Dodecahedron



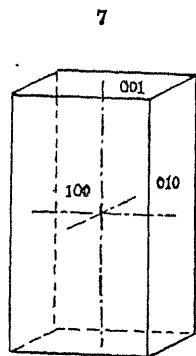
Trapezohedron



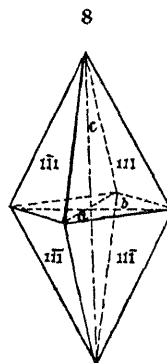
Tetrahedron



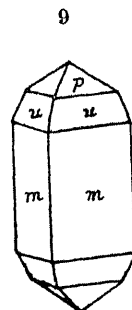
First Order Prism



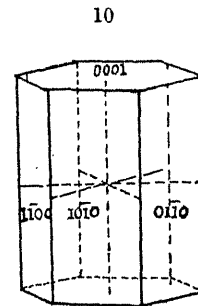
Second Order Prism



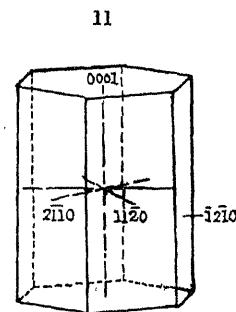
First Order Pyramid



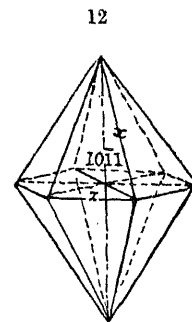
Zircon  
First Order  
Prism & Pyramids



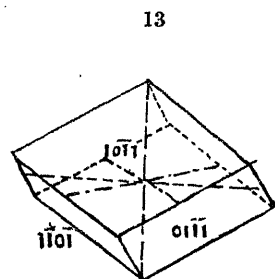
Hexagonal  
Prism  
1st Order



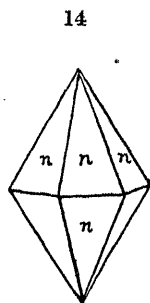
Hexagonal  
Prism  
2nd Order



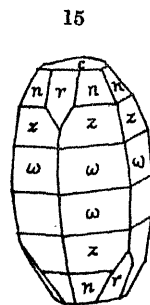
Hexagonal  
Pyramid



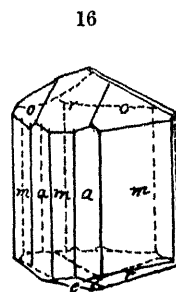
Rhombohedron  
Positive (Calcite)



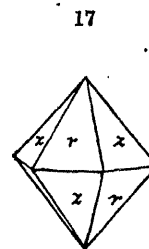
Corundum



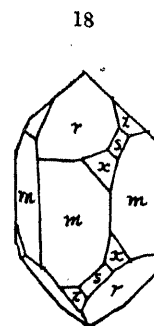
Corundum



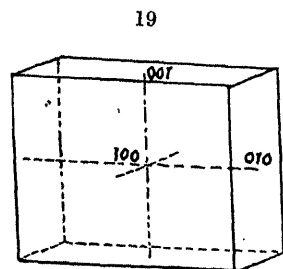
Tourmaline



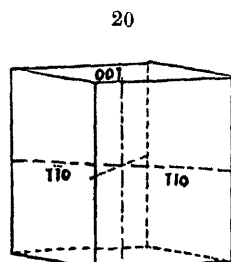
Quartz



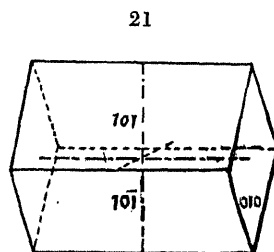
Quartz



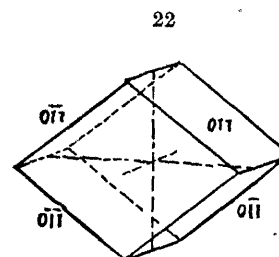
Macro-, Brachy-  
& Basal Pinacoids



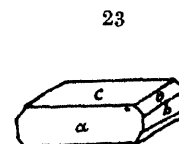
Prism & Basal  
Pinacoid



Macrodome &  
Brachy Pinacoid



Brachydome &  
Macropinacoid



Orthorhombic  
Barite





are amenable to such treatment, e.g. yellow topaz becomes rosy pink on heating, amethyst becomes yellow on heating and is sold as topaz. Diamond when exposed to radium becomes green. Size, transparency and glossiness are also important factors that create distinction in gems, e.g. a five carat and a ten carat stone of aquamarine do not show the same colour. In turquoise the lack of transparency gives some characteristic colours. Glossiness is more appreciated in opaque material.

### GEM-STONES UNDER ULTRAVIOLET LIGHT

When a ruby or red spinel is exposed to ultra-violet rays in a dark room the stones glow with a wonderful red light. Similarly, when a handful of diamonds is held in front of an ultraviolet lamp, some shine with a cornflower blue, some with a soft yellowish or green. This is called fluorescence as it was first seen in fluorite.

Play of colours is another feature as revealed by opal, due to a variety of internal hues, and also by labradorite. The cause of this phenomenon is the interference of light caused by minute cracks or inclusions within the mineral. This is different from 'fire'. Opalescence is shown by opal and moonstone and is due to milky or pearly reflections from the interior of the crystal.

### LUSTRE AND BRILLIANCY

The surface appearance of a mineral in reflected light is its lustre, and is governed by transparency, refractivity and structure of the mineral. There are two kinds of lustre, metallic and non-metallic. We are concerned with non-metallic lustre only for the gem-stones, and the following varieties may be noted.

*Adamantine* is typical of diamond and other minerals with high refractive index. *Vitreous* or *glassy* is possessed by quartz and glass. *Resinous* is the lustre of resin, and *greasy* denotes that of an oily surface. Pearly lustre is

characteristic of pearls and mother of pearls. A silky lustre is characteristic of minerals with a fibrous structure. Lustre may be useful in the determination of uncut material.

Brilliancy is brought out by cutting and polishing. The rough stone is very often a pebble, but its lustre is brought out by cutting. Brilliancy also depends on transparency, lustre and the fineness of the polish. A hard stone takes a better polish and a stone with a greater refractive index possesses greater lustre and brilliancy.

### TRANSPARENCY OR DIAPHANEITY

A substance is transparent when it transmits light through it, so transparent minerals allow light to pass through them freely, e.g. rock crystal. When light is only feebly transmitted through a mineral which does not permit any object to be seen through it, it is called translucent. The majority of gem minerals are transparent, and particularly of the precious stones.

### FLUORESCENCE AND PHOSPHORESCENCE

Certain minerals glow or become luminescent on heating or when subject to the influence of ultraviolet rays, X-rays, Cathode rays, etc. It is well observed in the dark and the luminescent colours differ from those of unexcited minerals. At times these colours may be interesting and spectacular. A substance is said to fluoresce, if the luminescence is present only during the period of excitation, and a substance is said to 'phosphoresce' if the luminescence persists even after removal of the cause of excitation. The diamond, ruby, opal and amber show luminescence to a marked extent. Both the above phenomena could be demonstrated by the use of mercury vapour and argon lamps. At times luminescence phenomena are useful in the identification of gem-stones. Similarly, diamonds are transparent to X-rays, whereas glass imitations are opaque.

## ELECTRICAL PROPERTIES

The following electrical properties are possessed by certain gem-stones, e.g. frictional electricity, pyroelectricity and piezo-electricity.

*Frictional electricity.*—Diamond, tourmaline, topaz are positively electrified when rubbed with a cloth, whereas amber develops a negative charge.

*Pyro-electricity.*—Tourmaline is an excellent example of a pyroelectric mineral. The crystal when heated develops positive and negative charges on its opposite ends. The test is done by gentle heating of the crystal bringing it into contact with a conducting medium, when the electricity developed during the heating is discharged. Quartz also exhibits pyroelectricity.

*Piezo-electricity.*—Electrical charges are developed in certain minerals by application of pressure, e.g. quartz and tourmaline. Properly oriented sections of quartz are used for frequency control in electric and radio apparatus.

## CHAPTER VI

### PHYSICAL PROPERTIES

SOME of the physical properties of gem-stones have already been dealt with under colour, lustre, etc. Now we may proceed to consider the structure and other related properties of gem-stones.

The structure of minerals may be (a) amorphous with no definite structure, e.g. opal and glass; (b) cryptocrystalline whose structure is revealed only by the microscope, e.g. agate and flint, and (c) crystalline aggregates, e.g. coarse marble. In a study of gem-stones, we are concerned with crystalline aggregates and crystals, whose internal structure is expressed by their external form or faces and crystals are more valuable for gems, because they are better formed than the aggregates and are distinct.

## HARDNESS

Hardness is an important character of gem-stones, because the durability of the gem-stones depend on this character. Hardness is defined as the resistance which a mineral offers to abrasion or scratching. When a crystal or quartz is used to scratch a crystal of calcite, a deep scratch and white powder are left on the calcite. When it is reversed no scratch is seen on the quartz. Minerals are tested in this manner and arranged according to their hardness. A scale of hardness in ascending order has been devised to fix the hardness of minerals, known as Moh's scale of hardness, which is given below.

- |              |                          |
|--------------|--------------------------|
| (1) Talc     | (6) Felspar (Orthoclase) |
| (2) Gypsum   | (7) Quartz               |
| (3) Calcite  | (8) Topaz                |
| (4) Fluorite | (9) Corundum             |
| (5) Apatite  | (10) Diamond             |

The values assigned are only relative hardness. Other supplementary tests for hardness are as follows:—

Finger nail up to  $2\frac{1}{2}$ , copper coin up to 3, knife blade up to  $5\frac{1}{2}$ , window glass  $5\frac{1}{2}$ , steel file 6-7.

Gem-stones have their hardness at the top of the above list; these minerals are sold as a scale of hardness. To find the hardness of a stone, we must find the highest mineral in the scale that it will scratch and the lowest by which it can be scratched. Then the hardness of the mineral or gem-stone could be fixed. Hardness tests require some practice and are not simple. The power of abrasion will also depend on the sharpness of the scratching point and the smoothness of the surface scored. The hardness of rough or cut gems is best done by hardness pencils or points. They are holders with conical shaped fragments of the test minerals mounted on ends. When applying this test the scratch should be as short as possible and should not be on a prominent face. The scratch should be very small and using a lens with an

unmounted gem and tests should be made on the girdle of the stone. A light scratch on the girdle can be easily concealed by the setting of the stone. Hardness of the stones could also be tested by the use of a file or knife-point ( $H = 6\frac{1}{2}$ ), and by trying it on a sheet of glass ( $H = 5\frac{1}{2}$ ). By this means a glass imitation could be easily tested. The harder the stone, the easier it scratches glass. Hardness determination should be done with caution, otherwise a good stone may easily be spoiled. Hardness may also vary on different faces in crystals, e.g. kyanite, where the direction parallel to the long axis is softer than the one perpendicular to it.

Harder minerals scratch or abrade softer ones, so good mineral specimens or gems should not be jumbled together in a box lest the softer may suffer, e.g. amber and pearls. The hardness of a mineral also determines its durability. A gem should at least be harder than quartz to retain its beauty, brilliancy and splendour. The diamond, ruby, sapphire and emerald are harder than quartz. The softer stones are often considered semi-precious (see Table of Hardness for Gem-stones, pp. 166-167).

### CLEAVAGE

This is related to the internal structure of crystals and forms an important character. It is the property of easily splitting or separating along definite planes, known as the cleavage planes, e.g. mica which has a perfect basal cleavage. Crystals of different minerals have different degrees of cleavage, which also serve in determining minerals. The different degrees are known as 'perfect', 'imperfect', 'distinct' or 'indistinct'. Cleavage is also a property usually taken advantage of in cutting gem-stones, e.g. diamond. Gem-stones with easy cleavage should be handled carefully while being cut or polished. Cleavage is not related to hardness and is possessed by both soft and hard minerals.

*Parting* planes are somewhat akin to cleavage and are known as false cleavage. Corundum has basal parting.

*Fracture* refers to the nature of the surface obtained, when a mineral has no definite cleavage or parting. Fracture is conchoidal when the fracture surface is curved or shell-like, e.g. in glass or quartz. Fibrous minerals break with a splintery fracture, e.g. jadeite.

### SPECIFIC GRAVITY

The specific gravity of a substance is the ratio of the mass of any quantity of the substance to the mass of an equal volume of water at 4°C. The density of a substance is its mass per unit volume of the substance; hence the specific gravity of a substance can also be expressed as the ratio of its density to that of water at 4°C. In C.G.S. units, the density of a substance is its mass in grams of one cubic centimetre of the substance and since the mass of one cubic centimetre of water at 4°C. is one gram, the specific gravity is numerically equal to the density.

The specific gravity of a substance varies with temperature, the variation being considerable where a wide range of temperature is involved. In determining the specific gravity accurately, it is necessary, therefore, to make corrections for temperature and also for air buoyancy. When working at ordinary room temperatures, however, the theoretical corrections for temperature and air buoyancy are less than the experimental error involved in the determination of specific gravity. Hence they may be ignored. Moreover, these corrections never affect the determination to the second decimal place.

The specific gravity of a mineral is of great importance as it has a constant value for each mineral species and could be determined accurately without injury to the gemstones. It forms a valuable aid in determining gemstones, e.g. quartz 2.65 and diamond 3.52.

## METHODS OF DETERMINING SPECIFIC GRAVITY

The substance is first weighed in air and then in water. In water it weighs less due to the buoyancy caused by the displacement of an equal volume of water according to the principle of Archimedes. The difference between the weight of the substance in air and its weight in water, i.e. the loss of weight is the weight of a volume of water equal to that of the substance.

$$\text{Hence sp. gr.} = \frac{\text{Weight of stone in air}}{\text{Loss of weight in water}}.$$

Since gem-stones are very small when cut, a delicate balance has to be used at least to one milligram. The usual methods for determining the sp. gr. involve the use of (1) the Chemical Balance, (2) the Pycnometer, (3) Heavy Liquids and the Westphal's Balance, and (4) the Jolly's Spring Balance.

### (1) THE CHEMICAL BALANCE

The stone is suspended from the lower hook of the left stirrup of a balance by a thin cotton thread and its weight determined in air. Let this be  $W_1$  grams. Next the weight is determined with the stone immersed completely in water in a beaker, placed on a hydrostatic bench placed on the left pan taking care that the pan does not touch any part of the bench. Let this be  $W_2$  grams. The loss of weight is then  $W_1 - W_2$  grams. Therefore, the sp. gr. of the stone is

$$\frac{\text{Weight of stone in air}}{\text{Weight of equal volume of water}} = \frac{W_1}{W_1 - W_2}.$$

This method could be used for fairly large and medium specimens but not for cut and small stones, and also takes much time.

### (2) THE PYCNOMETER

The Pycnometer or the specific gravity bottle is merely a bottle with a ground in stopper having a fine bore through it and it is so constructed that it has a specified volume,



say 50 or 100 c.c. When filled up to the top of the hole at a definite temperature, it may be used to determine the specific gravity of a substance in the form of loose granular material which can be had in sufficient quantity. This method involves three or four weighments in the balance and is not very much used. It is accurate but slow, and may be used with powdered material, fragments and cut stones. An appreciable amount of material must be used.

The weight  $W$  of the empty, clean and dry bottle is first determined with a Chemical balance. The substance which must be quite dry is placed in the bottle so as to fill about half or one-third of the volume of the bottle. The weight  $W_1$  is again taken. The weight of the substance is

$$= (W_1 - W) \text{ grammes} \dots \dots (1)$$

The bottle is now nearly filled with distilled water and gently shaken so as to dislodge all the air bubbles. It is next completely filled up with distilled water, its outside well dried and again weighed. Let this weight be  $W_2$  grammes. The substance is now removed from the bottle, which is again filled with distilled water and weighed after drying the exterior. Let this be  $W_3$  grammes.

The weight of bottle + bottleful of water + substance if it were placed outside =  $W_3 + (W_1 - W)$  gm. (2).

The weight of bottle + bottleful of water + substance placed inside the bottle =  $W_2$  gm.  $\dots (3)$ .

The difference between (2) and (3) above is the weight of water displaced by the solid substance—the volume of the displaced water being equal to that of the substance.

The specific gravity of the substance

$$= \frac{W_1 - W}{W_3 + W_1 - W - W_2} \dots \dots (4)$$

To ensure greater accuracy by avoiding error due to air films after introducing the substance and water, the latter

may be gently boiled and again cooled before determining the weight.

### (3) HEAVY LIQUIDS AND WESTPHAL'S BALANCE

\* This method is particularly useful when the mineral is not obtainable in sufficient quantity. A number of heavy liquids, organic as well as inorganic, are used which could be diluted to give a solution of any given specific gravity. The gem whose specific gravity is to be determined is immersed in the liquid and it is noticed whether it sinks or floats. The liquid has to be diluted or concentrated until the stone neither sinks nor floats. The specific gravity of the liquid could be easily determined by the Westphal's balance. The value obtained for the liquid is obviously the specific gravity of the stone. It could be used for stones whose specific gravity does not exceed the specific gravity of the liquid used.

#### WESTPHAL'S BALANCE

It has a graduated beam and from one end of it a weighed sinker is suspended in the liquid contained in a cylinder. When the sinker is properly immersed in water, the beam is horizontal as indicated by the pointer on the left hand side. When the liquids are substituted in the cylinder—weights or riders are adjusted on the beam until the sinker neither rises nor sinks. The specific gravity of the liquids can be directly read from the positions of the riders on the beam.

The Westphal's balance could also be used to determine the specific gravity of solids, insoluble in water. The sinker is removed and the pans are attached to the screwed end of the beam. The cylinder is filled with water at 15°C. [so that the lower pan is completely covered during the whole of the time it is swinging. The adjustable weight is now turned until the beam is again in equilibrium.

The substance whose specific gravity is to be determined is now placed on the upper pan and the rider weights employed as described above until the equilibrium is restored. The reading obtained now represents the weight 'in air'. The substance, presumably in pieces, is now transferred from the upper to the lower pan. In the case of a powdered substance, the pans could be substituted. The riders or weights are again adjusted in the usual way and the resultant reading gives the weight of the substance in water.

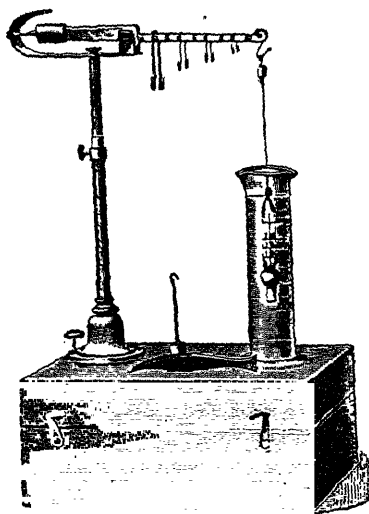


FIG. 24.  
Westphal's Balance.

The calculation is now made as follows:—

$$\text{Sp. gr.} = \frac{\text{Weight in air}}{\text{Weight in air} - \text{weight in Water}}.$$

This method combines accuracy with reasonable rapidity, and is used with small stones, whose specific gravity does not exceed the maximum specific gravity of the liquids used.

The following liquids are used whose maximum specific gravity is given and which could be lowered by diluting with suitable liquids:—

	Sp. gr.
1. Methylene iodide .. ..	3.31
2. Potassium mercuric iodide (Thoulet's solution) ..	3.196
3. Cadmium borotungstate (Kleins' solution) ..	3.284
4. Barium mercuric iodide (Rohrbach's solution) ..	3.58
5. Thallium formate and Thallium malonate } (Clerici's solution)	.. 4.65
6. Thallium silver nitrate .. ..	5.0

A set of standard specific gravity liquids with fixed intervals could be kept ready by diluting any one of the first five liquids. It could be used without the Westphal's balance by matching liquids with a series of stones of known specific gravity. This permits a quicker mode of determining the specific gravity. Methylene iodide has a density of 3.3. It is a clear pale-yellow liquid. Stones with higher specific gravity than 3.3 will sink and those with less than 3.3 will float. It is miscible with benzene in all proportions, and so a series of liquids from 0.88 to 3.33 could be prepared. But there may be variation in the values due to the presence of impurities, cavities or flaws in the stones and also due to variation in composition (chemical). With the larger stones Jolly's balance could be used. (See Table on pp. 166-167 for a List of Gem minerals with specific gravity, etc.)

#### (4) JOLLY'S SPRING BALANCE

This enables a most rapid determination of specific gravity of a gem, but the method is not quite so accurate as described in (1) and (3), but results obtained are usually good enough for determination of gems and could be used with advantage with larger stones.

It consists of a spiral spring suspended vertically from a horizontal rod at *O* and hangs against a graduated mirror.

$P_1$  and  $P_2$  are two pans suspended from the lower end of the spring. Above pan  $P_1$  is an index head  $B$ . The lower

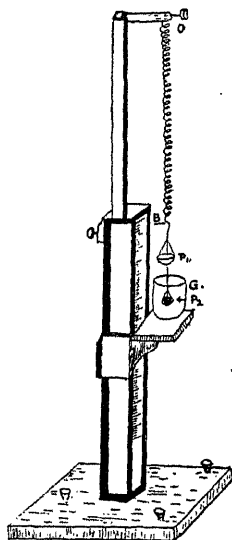


FIG. 25.  
Jolly's Spring Balance.

pan  $P_2$  and attachments are immersed in water in the cylinder  $G$ . Reading  $a$  is taken on the graduated scale after properly adjusting the apparatus, so that the index head lies against the upper part of the scale. The stone is then placed in the upper pan, the amount of immersion is adjusted to the same level as before by lowering the level of water. Reading  $b$  is now taken. The stone is now placed in  $P_2$  inside water, and the level of water again adjusted as before, and reading  $c$  is now taken.

Reading  $a$  is proportional to the total weight of the spring + its suspension.

Reading  $b$  is proportional to the total weight of the spring + its suspension + weight of specimen in air.

Reading  $c$  is proportional to the total weight of the spring + its suspension + weight of stone in water.

Weight of specimen in air =  $(b-a)$

Weight of specimen in water =  $(c-a)$

Loss of weight =  $(b-c)$

$$\text{Sp. gr.} = \frac{b-a}{b-c}.$$

## CHAPTER VII

### OPTICAL PROPERTIES

IN addition to the physical properties already dealt with there are a few other optical properties, which are of great value in the determination of gem-stones. These properties are determined by optical instruments such as the dichroscope, refractometer, and the polarizing microscope. A brief explanation of the essential properties of light is given before the optical instruments and their uses are described.

#### REFLECTION AND REFRACTION OF LIGHT

When a ray of light falls on a mirror or a polished surface, it is reflected so that the angle of incidence  $XON$  is equal to the angle of reflection  $YON$  (see fig. 26) and that the reflected and incident rays lie in the same plane with the normal to the reflecting surface.

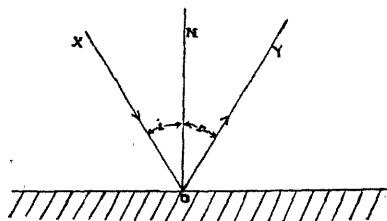


FIG. 26.  
Reflection at a plane surface.

When light travels from one medium to another, there is in general an increase or decrease in velocity, which results in the phenomenon of refraction, i.e. a change in the direction of propagation. In the case of transparent gems, the reflected light is not so important as the refracted light. When a ray of light passes into water obliquely, the path of the ray is not straight, but bent. When a ray of light travels from a rarer to a denser medium, as in the above case, the ray is bent towards the normal to the plane of contact between the two media. Naturally, the reverse will be the case when a ray of light travels from a denser to a rarer medium. It is then bent away from the normal. In fig. 27 the angle of incidence  $CXO$  is called  $i$  and the angle of refraction  $DXN$  as  $r$ . The law of

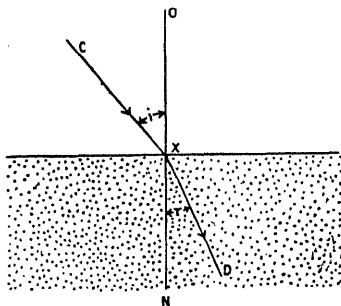


FIG. 27.

Refraction at a plane surface.

refraction is: The incident and refracted rays lie in the same plane, and the ratio of the velocities in the two media, and the ratio between the sines of the angles of incidence and refraction,  $i$  and  $r$ , are constant for the media concerned.

$$n \text{ (index of refraction for water)} = \frac{V \text{ (air)}}{V' \text{ (water)}} = \frac{\sin i}{\sin r} = 1.333$$

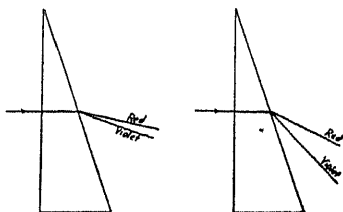
The constant is the index of refraction, the velocity of light in air being  $l$ .

For water R.I. = 1.333 and for diamond 2.42. It is evident that gem-stones could be identified by the deter-

mination of the value  $n$ . Before discussing the methods of determining  $n$  (R.I.) another property has also to be considered.

### DISPERSION

When a ray of light is passed through a glass prism, it is resolved into component colours, in which red is refracted least and violet most, with orange, yellow, green and blue occupying the intervening space in the band of



Glass. FIG. 28. Diamond.

colours, which is known as the 'spectrum'. This is because the velocity of the red ray is greatest and that of violet least. On account of this property of dispersion, the index of refraction is best determined with light of a definite colour or monochromatic light.

This difference in the velocities of red and violet lights in passing through a medium indicates the strength of the dispersion of that medium or substance. It is usually expressed as the difference of the refractive index of the two rays. Diamond has three times the dispersion of glass, which produces the 'fire' of this gem. The component colours of white light in passing through diamond are widely dispersed, and pure colours may be seen on emergence under favourable conditions. Substances like glass which has a low dispersion have little or no 'fire'.

### TOTAL REFLECTION AND THE CRITICAL ANGLE

When light travels from a denser to a lighter or rarer medium the ray is bent away from the normal. The angle



of incidence  $I$  is smaller than the angle of refraction  $R$  in the rarer medium. For a certain angle of incidence  $i$

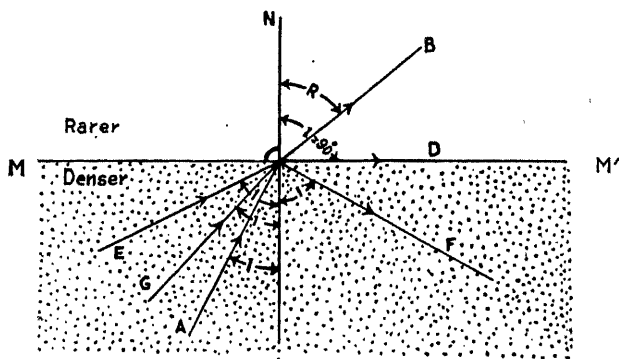


FIG. 29.

Critical angle and total internal reflection.

in the denser medium, the angle  $r$  in the rarer medium is equal to  $90^\circ$ , when the ray of light will just graze the surface between the media. For any angle greater than  $i$ , i.e.  $I$ , the light ray cannot emerge and is reflected back within the denser medium. This is known as the phenomenon of total reflection. All rays striking on  $MM'$  with the incident angle greater than  $i$  will suffer total reflection.

The value of the critical angle is expressed by the formula  $\sin i = \frac{1}{n}$  where  $n$  = index of refraction, and  $i$  = critical angle. The higher the value of  $n$ , the smaller is the

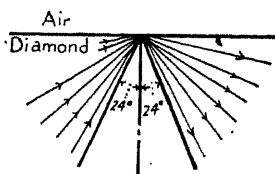


FIG. 30.

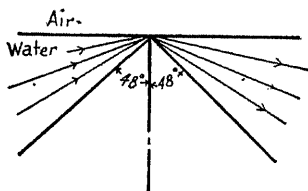


FIG. 31.

Total reflection and the critical angle.

critical angle and more light will be totally reflected within the substance. For diamond  $n = 2.42$  and  $i = 24^\circ 26'$ ; for water  $n = 1.33$  and  $i = 48^\circ 36'$ . The low value of critical angle in diamond causes total reflection more easily and because of repeated total reflection in cut stones, the brilliancy is very much enhanced. The reverse is the

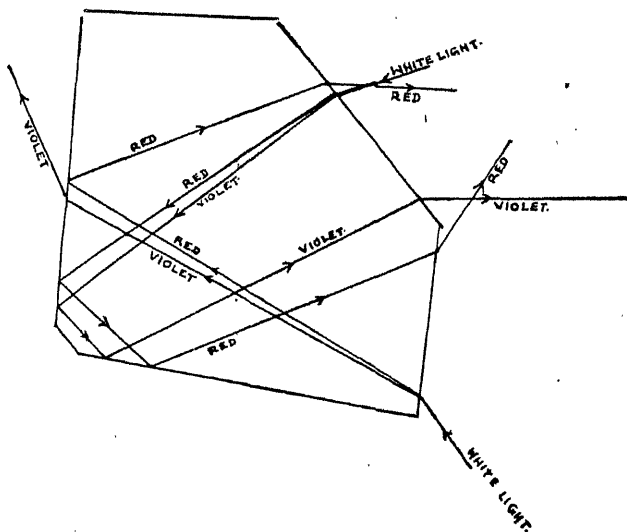


FIG. 32.

Refraction and internal total reflection within a brilliant cut diamond.

case in quartz. Repeated total reflection in cut stones with high dispersion tends to improve the fire.

#### DETERMINATION OF REFRACTIVE INDEX

The determination of refractive index is one of the most accurate and easily applied tests to determine precious stones. There are three methods: (1) Approximate immersion method, (2) Becke's method, and (3) Refractometer method.

(1) *Approximate immersion method.*—In this method minute fragments are immersed in a series of liquids with known refractive indices. This could be only applied when a small fragment can be detached from the stone. It could be done in the case of whole stones in such liquids. A colourless stone is almost invisible when immersed in a liquid of the same refractive index.

(2) *Becke's method.*—This method allows the refractive index of the mineral to be matched with that of one or other of the liquids. This method also depends upon the total reflection of light. It is done on the polarizing microscope by immersion method and on all small fragments. The test is fully explained in texts of mineralogy.

(3) *The Refractometer method.*—This is the best, because of its accuracy and ease of operation. It can be used

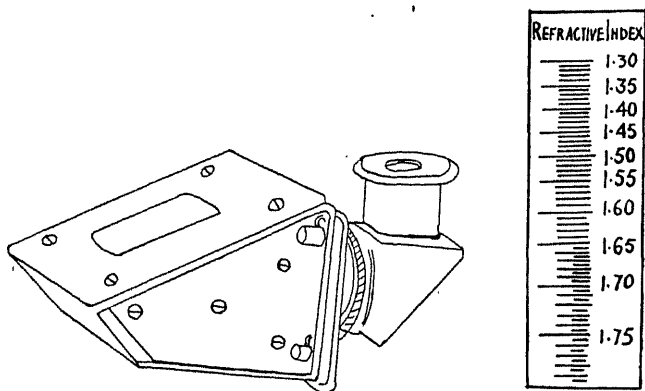


FIG. 33.

The Smith Refractometer (Model No. 2).      Scale of Refractometer (Model No. 2).

for both unmounted and mounted stones (faceted gems). The method depends on the principle of the total internal reflection of light. There are several types of refractometers of which Tully's and Herbert Smith's models are

popular. It would be preferable to use 'monochromatic light. The usual source of such a light is a non-luminous gas flame coloured by salt of lithium, sodium and thallium. In the case of gem-stones by using ordinary light sufficiently accurate results are obtained.

### TULLY'S REFRACTOMETER

The essential part of the instrument is a polished hemisphere of glass of a specially high refractive index, about 1.80 or 1.90 for yellow sodium light. The exposed surface of the sphere is a flat polished surface. The cut stone to be tested is placed on to the glass hemisphere *B*.

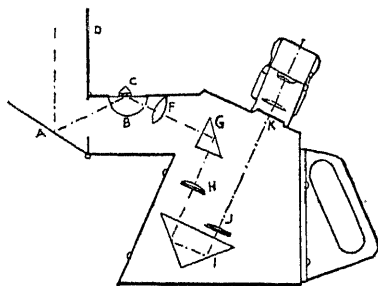


FIG. 34.

Cross-section through the Tully Refractometer.

To ensure optical contact between the stone and the hemisphere, a drop of liquid of high refractive index (methylene iodide 1.74) is placed between the two and the stone gently pressed down. A beam of light from the reflector *A* enters the hemisphere *B* to meet the stone *C* when it is reflected back into the eyepiece of the instrument. The light passes from a dense to a rare medium from the hemisphere to the stone. The light striking the stone at angles greater than the critical angle is totally reflected back into the hemisphere and after travelling through it and several prisms and lenses falls on a graduated scale *K*, which is viewed through the eyepiece. It illuminates

part of the scale and the rest remains dark. A sharp shadow line is seen across the field of view. The portion of the boundary between the lighter and darker parts on the scale is a function of the critical angle of the stone with reference to the sphere. This angle depends on the relative refractive index of the gem and glass. The refractive index of glass is known, the scale is so graduated that the position of the boundary of the illuminated area will indicate the refractive index of the stone. The divisions of the scale correspond to 0.01 but the index could be estimated to 0.001. The range of the instrument is limited by the refractive index of the glass used and may be as high as 1.88. The liquid used between the gem and the hemisphere must have its refractive index higher than that of the stone used. Methylene iodide could be used for stones with refractive index up to 1.74, whereas a solution of sulphur in methylene iodide permits indices up to 1.79 to be determined.

As light is reflected both from the liquid film and the stone two readings could be made on the scale—one due to the liquid and the other the stone. When examined under white light, the shadow line is not sharp, but is a coloured band or a narrow spectrum. The width of the band gives a measure of the refraction. If accurate results are required, monochromatic light should be used. But determinations are usually made with ordinary light. A coloured band is seen and readings should be made in the middle of the coloured band. If the stone has two indices of refraction, two boundaries are observed each denoting a different index.

The limitations are: (i) a flat polished surface is essential which faceted gems could give; (ii) natural crystal faces could be used, but they may not always be smooth; (iii) the gem must be gently pressed on the glass hemisphere, as it is very soft and liable to get scratched easily. After use it should be cleaned with a piece of blotting paper.

Repolishing should be done by the maker; (iv) another limitation is that a refractive index greater than 1.80–1.90 cannot be measured. The values of refractive index are usually given for sodium light. Herbert Smith has produced two forms of refractometer. The new model is a larger instrument and the delicacy of the readings has also been increased. The construction of the instrument is on the same principle as Tully's. The scale reads the refractive index for yellow (sodium light), directly to the second place of decimals, and in the higher values the longer intervals allow reading to tenth parts and even to the third place of decimals.

The range extends from 1.300–1.795 approximately and just includes the refractive index of corundum (sapphire and ruby), which adds much to the utility of the instrument. Methylene iodide with 1.74 and the liquid saturated with sulphur, R.I. 1.800, are also supplied in two bottles japanned on the outside.

The reading is to be taken at the part of the edge where the green passes into the yellow in the coloured band seen. Towards the bottom of the field another edge is seen, which corresponds to methylene iodide. If, on the other hand, the saturated liquid is used, no edge will be visible since its refractive index lies outside the range of the instrument. The colouration of the edge depends on the dispersion of the substance under examination.

### DOUBLE REFRACTION

When a ray of light passes into a cubic or amorphous mineral it passes out as a single refracted ray. But in minerals of the other five systems, it is not only refracted but is resolved into two rays, e.g. in calcite into ordinary and extraordinary rays. Many of the gem species are doubly refractive and when tested with the refractometer will show two distinct critical edges. In white light the separation will not be apparent unless the double refraction

is at least 0.02. A single plane facet is sufficient to give the whole of the optical properties, except possibly the sign of the double refraction.

### OPTICAL GROUPS

The crystal systems could be divided into optical groups, e.g. (1) Cubic and amorphous minerals—simply refractive or isotropic. These substances have one refractive index and light travels with the same velocity in all directions. These minerals are known as isotropic. (2) All substances belonging to other crystallographic systems are anisotropic; that is, the velocity of light varies with the direction in which it passes through them. They may have one or two isotropic directions, known as the direction of the optic axes. They are uniaxial, which include the tetragonal and hexagonal systems which have one optic axis; and biaxial—the remaining three systems, viz. the orthorhombic, monoclinic, and triclinic crystals, because they have two optic axes. For further details treatises on optical mineralogy could be consulted.

### PLEOCHROISM

The colour of a substance is due to certain portions of white light being absorbed in passing through it. This is also called selective absorption. The portion not so absorbed causes the colour that is seen. In isotropic substances light is absorbed equally in all directions. But in anisotropic substances, the absorption of light varies with the direction, as is also the case with the velocity of light. This variation in absorption with direction causes the phenomenon known as 'pleochroism'.

Ruby supplies a good example. When looked through parallel to the vertical or optic axis, the ruby has a much deeper red colour than when viewed in a direction at right angles to it. So rubies are better cut with the table parallel to the basal pinacoid. Uniaxial crystals have two principal indices of refraction and they possess two corre-

sponding colours. These substances are known as dichroic. Biaxial crystals have three principal indices of refraction, and they possess three corresponding colours, and the principle is known as trichroism. Pleochroism includes both dichroism and trichroism. In order to separate the colours an instrument called 'dichroscope' is used. It

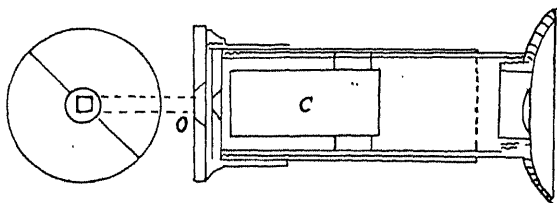


FIG. 35.

The cross-section of Dichroscope.

consists of a rhombohedron of Iceland spar mounted in a cylindrical tube. At one end is a small square opening and at the other end an eyepiece.

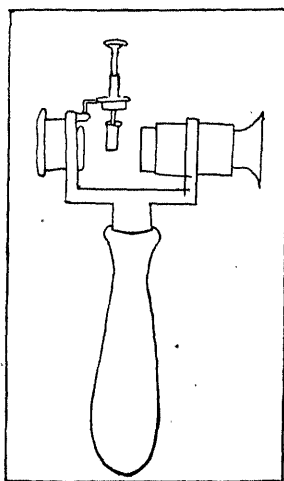


FIG. 36.

The Dichroscope with stone for testing.



When viewed through a dichroscope, two images of the opening are seen at the opposite end side by side due to the very strong double refraction of the calcite. The vibrations of the rays producing the two images are at right angles to each other and correspond to the ordinary and extraordinary rays. When a pleochroic crystal is placed in front of the opening, the two images are generally differently coloured. The colours of the images correspond to the colours transmitted by the two rays. If a ruby is viewed in this way, one image is dark red while the other is lighter in colour. In the direction of the optic axis the two images have the same colour. In a particular direction there will be maximum difference in colour. In biaxial substances there are three principal directions at right angles to one another in which the absorption is different. The dichroscope can reveal two absorption colours at one time. To observe the three absorption colours, the specimens must therefore be viewed parallel to two of the principal directions. When thus examined there will be four images, which will include the three principal absorption colours and the fourth being a repetition.

### THE PETROLOGICAL MICROSCOPE

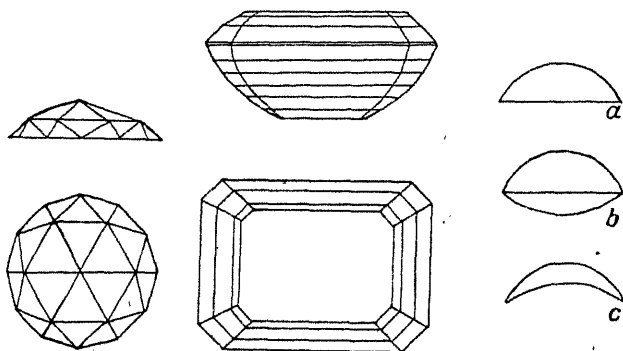
Pleochroism could also be determined by the microscope using only the polarizer. On rotating the pleochroic substance placed on the microscope stage, first one colour and then the other will be seen at angles of  $90^\circ$ . But in the dichroscope the colours are seen side by side, and very slight variations could be easily recognized. Since pleochroism is an absorption phenomenon, the colours also vary with the thickness of the specimen. The pleochroism is a property that is also an aid in the determination of gem-stones; for instance red garnet and spinel, used to imitate ruby, could be very easily found out because ruby is dichroic while garnet and spinels are not.

## CHAPTER VIII

### GEM-CUTTING AND POLISHING

MOST of the gem-stones are won as waterworn and damaged or rounded pebbles, though some good crystals may also be obtained. The value and beauty of gem-stones are very much enhanced by the proper cutting of facets, because the optical properties are then brought out to the best advantage. In-cutting it is always the aim to maintain the symmetry of the crystal.

The first attempts at gem-cutting were to smooth off or round off the stones and polish them by crude methods. Gems were also drilled and used as drops. The old process of cutting is still extant in the various types of cabochon cuts, which include the following: Convex cabochon, lenticular cut, high cabochon, hollow or concavo-convex cabochon. They are illustrated below.



Rose cut.

FIG. 37.  
Step cut.  
Trap cut.

Cabochon cut.  
(a) Simple.  
(b) Double.  
(c) Hollow.

The above cabochon cuts are suitable for stones that have a sheen as the tiger's eye, a play of colours as in opal,

opalescent as in moonstone and asterism as in 'star' stones. Stones that depend mainly on their colour or markings are cut in this way, e.g. garnets. The dark garnet requires a hollow cabochon cut to give a pleasing colour or, due to its thickness, it will appear very dark.

### FACETED CUTTING

The art of cutting smooth plane surfaces of geometrical design and symmetry on gems has been credited to Louis de Berquem of Bruges, Belgium. The discovery was made about 1456 or 1476, but it is also considered that it was known and practised earlier in Italy and France. 'According to Henri Polak, a Venetian craftsman, Vincenzo Peruzzi was probably the first to cut the diamond in the shape now known as the "brilliant".'

### FORMS OF CUT STONES

The 'rose cut' was then developed and used in diamond cutting. It is not much used now except in the case of small stones. It has a flat base, with triangular facets to the number of 12<sup>1</sup> or 24 or 32, which terminate at a point, and are grouped about the upper part of the stone. The outline of the stones may be circular, elliptical or oval. In some cases a double rose cut is given an upper and a lower portion. (See Fig. 37.)

The 'brilliant' cut, introduced about the end of the seventeenth century, has been extensively used for the diamond, since it brings out to marked advantage the remarkable fire and brilliancy of the gem. The octahedron is the basis of this cut. The upper and lower parts of a natural octahedron crystal are smoothed off and polished. The upper face is known as the 'table'—much wider than the lower facet known as the 'culet'.  $\frac{3}{8}$  of the height is removed from the upper part and  $\frac{3}{16}$  from the lower part.

In large stones it is done by sawing. The portions removed could be converted to smaller stones. (See fig. 38.)

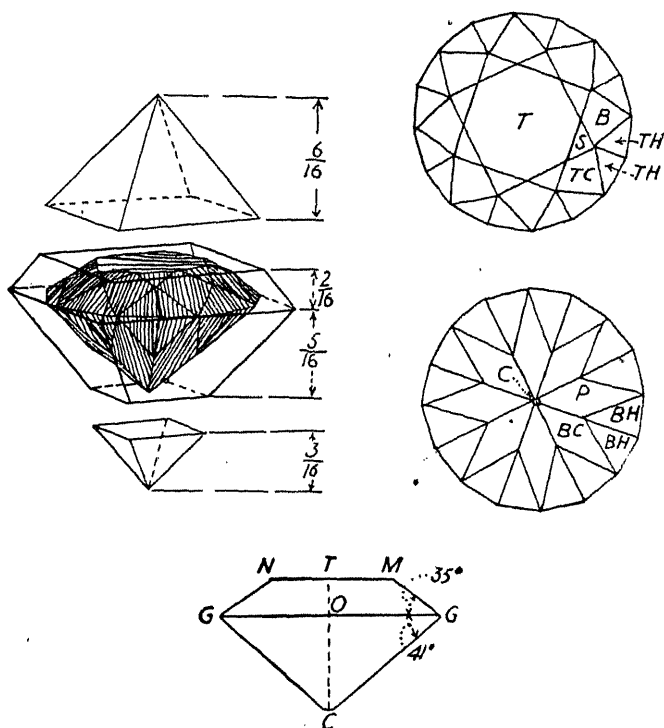


FIG. 38.  
Brilliant cut.

The portion above the girdle is 40% of the portion below the girdle. The upper portion is known as the 'crown' or 'table' and the lower part 'pavilion' or 'base' or 'culet'.

#### NAMES OF FACETS

The uppermost facet, 'T' is the table, and the lowermost 'C' the culet. Omitting these, there may be 56 facets,

which may be also increased to 64 or 72 or even 80 facets. All these facets have been given definite names. The 58 facets are known as below:

- (1) Table 'T'
- (2) 8 Star facets 'S'
- (3) 4 Bezel or top main facets 'B'
- (4) 4 Top corner facets 'TC'
- (5) 16 Top half or break facets 'TH'
- (6) 16 Bottom half 'BH'
- (7) 4 Bottom corner facets 'BC'
- (8) 4 Pavilion or bottom main facets 'P'
- (9) Culet 1 'C'

The cutting of diamond in order to exhibit its optical properties to the best advantage has been evolved upon long and practical experience. The following relations are maintained in the cutting: Thickness TC from the table to culet is 60% of the spread GG at the girdle. TO may vary between  $\frac{1}{3}$  to slightly less than half of OC. Width of the table NM may vary from 40–60% of the spread.

The angles made by the main upper facets with the plane through the girdle will be from 35–37°, whereas the lower main facets show an inclination of about 41°. It has been found by experience that the maximum brilliancy can be obtained when the incident and emergent rays are perpendicular to the table. Several investigators have given the angles and relationships that must be observed to obtain the ideal brilliant cut for different gems. But to obtain the best effects, brilliancy cannot be the sole criterion in cutting a stone, as the ratio of the cut stone to the uncut stone has also to be considered. So the data gathered from practical experience are found more valuable in cutting stones.

In a brilliant cut diamond, the light entering through the crown strikes the lower facets at angles greater than the critical angle which is 24° for diamond. So after repeatedly

undergoing total reflections, the light emerges from the stone on which the changing flashes of fire are seen.

### MODIFICATIONS OF THE BRILLIANT CUT

The brilliant cut has many modifications. The double brilliant or Lisbon cut has 74 facets. The half brilliant is a simple form, used for smaller stones. The trap brilliant or step brilliant has 42 facets. The Portuguese cut has 2 rows of rhombohedral and 3 of triangular facets on both crown and base. The star cut has a hexagonal table bordered by 6 facets in the shape of equilateral triangles, forming with the table a six-rayed star.

In cutting, attempts are also made to retain the maximum size of the stone but symmetry and beauty of form are not to be sacrificed. The brilliant cut is also used for ruby, sapphire, emerald and zircon. They are also cut with square outlines and fewer facets as in emerald. Stones are also cut in numerous other shapes, e.g. oval, elliptical, pear-shaped, etc. 'Melee' is a term applied to stones cut from small fragments of the diamond. 8-16 stones make a carat and the stones have 58 facets. Still smaller stones are called small 'melee', and 400 stones make a carat.

Coloured stones—Step, trap and cushion cuts are commonly used with coloured stones, e.g. emerald and tourmaline.

### CUTTING OF GEMS

Diamond-cutting is the most difficult due to its superior hardness. Diamond cutters form an aristocracy among gem cutters. Those engaged in cutting stones other than diamonds are known as gem cutters or lapidaries. The principal diamond-cutting centres used to be in Belgium, Germany and Holland. Antwerp in Belgium used to have the largest number of cutters, about 20,000, Germany about 6,500 and Holland about 4,000. But after the invasion of Holland and Belgium by Germany the cutting

industry has been very much disorganized. Gem-cutting also flourished in Germany—Idar Oberstein. In America also there used to be many cutting centres, where diamonds for industrial purposes were cut and shaped. Gem-cutting establishments have sprung up in South Africa and in the United States.

### HISTORY OF GEM-CUTTING

As gem-stones had their origin in the East, i.e. India, gem-cutting was also prevalent in the East. Tavernier (1665) travelled extensively in India in the seventeenth century buying gem-stones. He visited all the diamond mines of India between the years 1636–62 and he also stole the stone now known as the 'Hope' diamond. According to him the gem-cutting industry in India flourished from ancient times. He found a large number of diamond cutters at the Raolkonda mines; Karwan on the main road to Golconda was the place where the diamond cutters and polishers lived. Each of them was supplied with a wheel of steel about the size of a dinner plate, and they worked on one stone at a time. He also stated that the Indians were better in cleaving and splitting diamonds than the European cutters of the times. They did not use diamond dust for polishing as in Europe. According to Indian ideas, the cutting was mainly to remove faulty portions and a natural octahedron with polished faces was preferred. The general forms were the thick stones, table stones and thin stones: the first was known as the Indian cut. The oriental cutter followed the outlines of the rough stone and tried to reduce the loss of material to a minimum, whereas with the European cutter, the development of its properties is of prime consideration and economy of material is only secondary. In most cases the Indian cut stone passed into the hands of Europeans and were recut again. Some European cutters were also present in India.

In India, Jaipur is now an international jewellery centre and most of the dealers have foreign connexions. The lapidary work is done by hand driven machines, the charges are low and the stones are cut skilfully.

With the discovery of the diamond mines in Brazil in 1725 and subsequently in South Africa, the diamond mines of India became defunct and naturally the cutting industry gradually decayed. But soon a cutting industry grew up in Europe, that in Holland and Belgium getting mostly into the hands of the Jews. But in Panna State in India a small production is still maintained, and a small cutting industry still lingers. The Panna cutters are said to be proficient in cutting and they do the brilliant, the rose, the step cut and the briolette. A large number of Indian stones were always sent to Europe for cutting and polishing. In India there is still a small amount of gem-cutting at Bombay, Delhi, Jubbulpore, Ratanpur and a few other places. Much lapidary work is now done at Jaipur on emerald and other semi-precious stones, referred to previously.

The art of cutting was perfected by Louis de Berquem, who first used diamond dust for diamond-cutting in his polishing wheel. In the fifteenth century diamond-cutting made great strides, due perhaps to Van Berquem. Rose and rosette forms were introduced in the sixteenth century, which were very popular. The rose form was popular for a century and was replaced by the 'brilliant', which was discovered by Cardinal Mazarin about the middle of the seventeenth century.

The cutting industry was thriving very well in Belgium and the Netherlands, but the German invasion of these countries in May 1940 disorganized the cutting industry, which also very much upset the diamond industry. As a result cutting facilities became quite insufficient to meet the demands of cut stones. The small cutting establishments in England, South Africa and U.S.A. are being



expanded with the emigration of the refugees from the Low countries. Between 25,000 and 26,000 cutters were available in these countries as against 1,000 cutters in all the other countries put together. A cutting industry is also said to be developing in South Africa and Palestine. The expansion of the cutting industry is handicapped by the general scarcity of skilled labour. The pressure of much higher living costs render it difficult to work on anything except the larger stones, which could easily absorb the higher costs with the result the various small types of stones largely turned out in Antwerp and Amsterdam have become scarce.

Palestine is now handling small stones, specializing in stones from 0.5 to 0.02 of a carat. Now Palestine is the chief source of these stones. Some 2,500 workers were reported to be working there in 1942 in 14 establishments in Tel Aviv and 18 in Nathanya, with prospects of needing 1,000 more workers.

#### POST-WAR GEM DIAMOND-CUTTING INDUSTRY \*

(1) *Belgium.* 1946 may be regarded as the first year of resumed working in which the difficulties of reopening after the occupation were not present. In sympathy with the general level of world demand in the first ten months of the year, the Belgian industry was working to full capacity.

(2) *Holland.* The Dutch industry has not revived to the same degree as that of Belgium, as firstly before the war the Dutch specialized in large sizes in the production of which there is now greater competition and also due to reduced number of workers engaged in the industry associated by non-return of refugees.

(3) *Germany.* No revival.

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\* The Mining Journal, *Annual Review*, No. 1947, April 30th, 1947.  
'*The Diamond Industry in 1946*', pp. 19-23.

(4) *United Kingdom* shows slight improvement and employs some 650 workers.

(5) *U.S.A.* The industry has been stabilized with about 4,000 workers. At present the industry is working a three-day week occasioned by the falling of in demand after the Christmas trade.

(6) *Palestine.* The Palestine diamond industry employed an average of about 4,000 workers during 1946—an increase of 400 on previous year. The industry has shown remarkable progress.

(7) *Canada.* A small cutting industry is present, but most of its requirements are satisfied from external sources.

(8) Other centres for diamond-cutting are South Africa, France, Venezuela, Cuba, Brazil and British Guiana.

On January 1st, 1946, a new company registered in the Union of South Africa—Industrial Distributors (1946) Ltd.

## TECHNOLOGY

The war has brought about certain very important changes in the diamond industry, especially because of the enormous expansion of the scope for industrial uses of diamonds, whilst the cutting and distribution of gemstones has become of secondary importance. Sidney Ball estimates world consumption at 7.5 million carats. A large part of this increase is the result of more recent application of diamonds in the precision working of metals especially in the automobile and aeroplane industries and in wire drawing dyes. The preparation of stones for tools has grown to such an extent that in the U.S.A. and Great Britain, the cutting industry has been reorganized to provide the necessary skilled labour for the tool trade. Much fine lapidary work is also done in Russia for making ornamental objects. In China and Japan large balls of quartz are cut and polished. Lapidary shops are also found throughout the U.S.A.

The diamond-cutting processes involve five stages, consisting of inspection, cleaving, sawing, cutting, and polishing.

### (1) INSPECTION

First process consists of the examination of the rough stones regarding crystal form, shape, inclusions, cleavage cracks, flaws, etc., which have to be properly located. Then ideas as to the style of cutting, eliminating imperfections, etc., are arrived at. If the stone required sawing or clearing, the directions in which they have to be done are marked in Indian ink.

### (2) CLEAVING

Large stones are subdivided into smaller ones for commercial purposes. Inclusions, flaws, etc., are removed, and rough stones are brought to rough forms with the aid of the octahedral cleavage. To cleave a stone, it is mounted on the end of a specially designed stick, by the aid of a suitable hard cement. Next, a groove is made in the direction of the cleavage, as previously determined. If the octahedral faces are well developed, the octahedral cleavage could easily be recognized or the lines of growth or grain have to be determined.

The groove is cut by a diamond fragment with a sharp edge mounted on a stick, so that it could be easily manipulated. The stick, with the diamond to be cleaved, is then placed in a support with the knife-edge of a steel plate or cleaving iron, held with one hand in the groove or notch. The steel plate is given a sharp blow with a small hammer. The stone breaks or cleaves into two parts parallel to the face of an octahedron.

Although it may appear a simple process, cleaving demands most careful work or the stone may be easily damaged. The cleavage surfaces should be as smooth as possible, and no particle of diamond should be lost.

### (3) SAWING

To obtain the maximum portion of the gem-stone the diamond is divided into smaller ones by sawing it through the middle, which gives two stones of equal size. If it is sawed above the middle, two stones of unequal size are produced. The shape of the stones and the flaws or imperfections form the guide in the sawing. With large stones, both cleaving and sawing may be required. The smaller portions cut go into the 'melee'. The sawing is done with the aid of a thin phosphor bronze disc 2" or 3" in diameter revolving at a speed of 2,500-4,000 revolutions per minute. The diamond to be sawed is embedded in a metal cup-like holder with a mixture of plaster of Paris and glue. The portion to be removed is exposed, and is held mechanically against the edge of the bronze disc, which has been impregnated with diamond dust and oil. Sawing a one carat stone takes about eight hours and larger stones may take several days, but one man could supervise the work of about twenty sawing machines.

Diamond dust could be used to saw or cut diamond in certain directions, e.g. in faces parallel to crystallographic axes, i.e. faces of the cube. It is found impossible to saw the diamond, if the direction of cutting differs by a few degrees from that of a cubic face.

### (4) CUTTING

By cutting, the stone receives the rough shape or outline. It is now done mechanically and more rapidly than in former days. The stone to be cut or shaped is mounted in a brass holder called the 'dop' with a hard cement. The dop is then screwed to the chuck of a motor-driven lathe. A second stone, similarly fixed to a dop, is screwed to the end of a specially designed stick, and held against the one revolving on the lathe. The stone mounted on the stick serves as a cutting tool.

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A special non-metallic cement is used in mounting diamonds for cutting. It softens and melts when heated over a Bunsen burner, and hardens immediately when taken away from it. The hardening could also be hastened by dipping it into water.

The diamond-cutter has first to remove imperfections and then give the stones the desired shape or outline with the absolute minimum sacrifice of the gem. A special chuck is of great assistance to the cutter in moving the stones to the required position. It could be made eccentric and brought back to the centre easily. The cutter has to so shape the stone that it should be attractive and pleasing to the eye. Great care is also required to collect all powder and fragments, which are of great value for polishing.

#### (5) POLISHING

The cutting or grinding of the facets one by one and giving them a good polish is known as polishing. As has already been described, the facets must be symmetrically arranged and accurately inclined, which demand great skill, experience and a keen artistic sense on the part of the diamond cutter. Diamond polishers are of two kinds: (1) Lappers, and (2) Brillianteerers. The lapper cuts the eighteen fundamental facets, which are as follows: four top corner TC, four bezel facets B, a table T above the girdle, four bottom corner BC, and four pavilion P facets and the culet C below the girdle. The facets have to be cut at the given angles precisely to give the best results.

Then the stone is passed to the brillianteerer, who adds the remaining forty facets. Of these eight star S and sixteen top half TH facets are above the girdle, and the sixteen bottom half BH are below. This finishes a stone with the usual fifty-eight facets. In cutting these additional facets, the brillianteerer depends entirely upon his trained eye and does not use any gauges. Gauges are used by the lapper for cutting the facets with proper

inclinations and also to maintain exact parallelism between table, girdle and culet.

The lapping and brillianteing are done by holding the properly mounted stone against a rapidly revolving horizontal wheel of cast iron or skeif. Diamond dust mixed with oil is fed on the wheel, which rotates at the rate of 2,000 to 3,000 revolutions per minute. The dust has to be carefully prepared from the diamond powder and bits obtained from other operations and from fragments of poorer diamonds or bort. Four stones could be polished at a time on a skeif.

It has been found that there are variations in hardness in different directions and faces parallel to crystal axes; cubic faces have two optimum polishing directions, and facets parallel to these faces are the easiest to polish. Dodecahedral faces are parallel to one crystal axis, and each face has only one optimum direction. Octahedral faces are equally inclined to three axes and are most difficult to polish. But facets are not all parallel to a crystalline axis. The nearer a facet is to a crystallographic axis or face, the easier is it to polish. The sense of direction is usually determined by trial. An expert polisher recognizes these important features quickly and accurately.

These facets based on the long experience of the cutting industry are fully in accord with results of the studies on the atomic structure of diamonds by X-rays.

Diamonds are cut so that the table is parallel to a cubic, octahedral or rhombic dodecahedral face. The cutting industry refers to the planes as four, three or two point stones respectively.

*Dops*.—The holders to which stones are fixed for polishing are known as dops, which are of two kinds: (1) *Solder dops* and (2) *Mechanical dops*.

*Solder dops*.—It is a basin-like holder which is filled with an easily fusible alloy of tin and lead. While it is hot and pliable, the solder is shaped into a hemispherical

mound, and the diamond is placed at its summit. When the solder cools it becomes rigid and the stone is held rigidly in position. Only a small fraction of the stone is exposed at a time. Consequently while grinding and polishing the numerous facets, frequent remountings have to be done.

At present mechanical dops are widely used in lapping, and also in the brilliantteering of large stones. In the mechanical dop the stone is rapidly held by prong and clamps, and the stone does not change its position even when it gets heated during prolonged grinding. Remounting is also easier in mechanical dops. The lapper also gets a full view of the stone.

Semi-automatic machines have now been devised for polishing diamonds—the Stern-Coleman machine. It has micrometer gauges, degree finder and a tipping device. The machine is set for a certain amount of grinding after which the tripping device automatically removes the stone from the lap. 55–58% of the stone used to be lost in cutting formerly. A 10% reduction or saving has been made in the loss due to cutting by the introduction of sawing. An attempt to save a large part of the stone may result in a badly proportioned cut, which may very much reduce the value of the gem.

### CUTTING OF OTHER GEMS

The methods employed differ from those of diamond due to different physical properties and less hardness. The most important place has been Idar-Oberstein in Germany, where most of the people are employed in this industry. Those who cut gems other than diamonds are called *lapidaries*, but again a difference exists between gem-cutters and lapidaries. The gem-cutters use sandstone wheels, which are run by electric or water power and cut agate, quartz, opal, etc., which have a hardness of 7 or less. Lapidaries use carborundum wheels and electric power and

cut all gems except the diamond. For fuller description see *Kraus and Slawson*, pp. 102-112.

After the facets have been cut, the stone is then polished with tripoli or rouge on wooden cylinders or on canvas-covered wheels. The methods are also described in *Quartz Family Minerals*, by Dake, Flower and Wilson and *Jewellery, Gem-cutting and Metalcraft* by William T. Baxter, McGraw Hill Book Co., Inc. New York.

## ENGRAVING

It is a specialized branch of gem-cutting for the cutting of cameos, etc., requiring great skill. It is done by a small lathe into which suitable cutting tools are fitted. The stone is held against the rapidly revolving tool. Engraving and boring are done as home industries in Idar-Oberstein.

## SIZE AND WEIGHT OF GEMS

The usual units for weighing gem-stones are: (i) carat, (ii) grain, (iii) pennyweight, and (iv) grain. The carat is the most used in the gem trade in the principal countries of the world. It is 200 milligrams or  $\frac{2}{10}$  of a gram. It is also known as the metric carat. Generally the value of a gem-stone per carat increases rapidly with weight. Formerly, before the introduction of the metric carat, the carat had different weights in different countries.

London—0.2053 grams. Madras—0.2073 grams.

Florence—0.1972 grams. Amsterdam—0.2057 grams.

Now decimals of a carat are used instead of fractions. The term carat used for gems should not be confused with the carat used to denote the fineness of gold. Here a carat means  $\frac{1}{24}$  part and pure gold is 24 carats fine, i.e. 18 carat gold is  $\frac{18}{24}$  gold and  $\frac{6}{24}$  base metal.

Lapis lazuli, citrine, moonstone, amethyst, etc., are sold by the gram. Pennyweight (1.42 grams) may also be



used for gem-stones. The term grain is also in use. A pearl grain is  $1/24$  of the gram.

In India rati was used. Rati = weight of 1 seed of *Abrus precatorius* =  $\frac{1}{2}$  a carat, but it used to vary. Now international carat is in use, i.e. 0.200 grams, from 1913. (*Gemmologist*, January, 1936.)

## CHAPTER IX

### SYNTHETIC AND MANUFACTURED GEMS

SEVERAL gems are very precious and expensive and most people may not be able to go in for them. But it is natural for everyone to have a yearning to own precious or semi-precious gems and for the poorer classes to have some cheap jewellery. To cater to the varying buying capacities of people the following materials are also available in the market: (a) treated gems, (b) synthetic gems, (c) imitation gems, and (d) doublets and triplets.

The manufactured gems also include natural stones, whose qualities are modified or improved by artificial means. Their value is actually raised by such means. Those manufactured in the laboratory consist of synthetic rubies, sapphires and spinel.

*Treated gems.*—Some stones are amenable to treatment, which increases their beauty and value. The treatment consists of several methods, and the stones may be subjected to the following processes: artificial colouring, heat treatment, heat and pressure, radium treatment and special kind of mounting.

1. *Artificial colouring and staining.*—Some pale agates are improved by this process by soaking the agate in suitable solutions. The different layers of agate possess varying degrees of perviousness, which allows them to be coloured in various shades with a pleasing contrast. The agate is immersed in a solution of sugar or honey and then soaked

in sulphuric acid. The acid chars the sugar and the porous layers get different shades of brown and black. This is practised on a large scale in Idar-Oberstein. The best results are obtained with smaller specimens either roughly shaped or finished. Different colours could also be given by immersing it in different solutions. Agates with vivid colours are treated stones: (a) lemon yellow by soaking in hydrochloric acid and heating, (b) reddish colours by simple heating or soaking in solution of ferrous nitrate and heating, (c) green by using chromium and nickel salts, (d) blue colours by soaking it in a solution of potassium ferro-cyanide and then treating it with a solution of ferric sulphate, (e) organic dyes and solutions of other coloured inorganic salts could be used. By substituting artificial colours some stones are made more attractive and costly, e.g. Swiss lapis and German lapis which are stained quartz and jasper.

2. *Heat treatment.*—By heat treatment some stones improve their colour, e.g. yellow topaz, which changes to an attractive pink. The stone is packed in asbestos and carefully brought to a low red. heat and then cooled. Quartz, amethyst, and smoky quartz when heat treated resemble precious topaz and sell as Spanish topaz, false topaz, gold topaz, etc. The qualifying terms are even omitted and often sold as genuine topaz, but its name should be citrine.

Brownish and reddish zircons, when heated may become colourless or assume a blue colour. Colourless zircon has been long used as a gem, since it has high refractive index and strong dispersion resembling diamond to some extent. Colourless zircons are also known as Matura diamonds. Blue zircons are also popular. They are obtained in Indo-China, heat treated and cut at Bangkok, Siam. Heating it in an oxidizing or reducing atmosphere imparts different colours. The heating could also be done after cutting. The heating is done in charcoal furnaces and no chemicals

are used. Heat treatment has also been found to improve the colour of streaky rubies and some amethysts. The following stones on heat treatment give the colours noted against them.

Greenish beryl—bluish colour appreciated in aquamarine.

Dark blue tourmaline—pleasing green of emerald.

Dark green stones turn to lighter shades.

3. *Heat and pressure.*—Pressed amber or amberoid is an example. Small pieces of amber are selected according to colour, all the impurities are removed and heated to 200–250°C. with exclusion of air. It becomes soft and could be moulded to desired shape. After cooling it hardens when it is easily finished and worked for the market.

4. *Radium treatment.*—Gem-stones are also liable to some change of colour when treated under radium emanation. Colourless diamond after long treatment becomes green. Colourless and rose quartz are turned smoky brown, and the colour of decolorized amethyst may be restored. The changes caused by radium have not much practical application.

5. *Special mountings.*—The colour of a stone could also be improved by mounting stones over foils or coloured enamels.

**SYNTHETIC GEMS.** Synthetic gems resemble very much the natural stones as they have the same chemical constitution. They are also sometimes called 'scientific stones' but this term refers also to imitations. But the synthetic ruby and natural ruby consist of  $\text{Al}_2\text{O}_3$ , and have the same physical properties as regards hardness, specific gravity, cleavage, refractive index and so on. But certain incidental and characteristic features are found helpful in the identification of synthetic stones and differentiating them from natural stones.

The synthetic stones were originally made by fusing together fragments of the natural material, and the stones were known as reconstructed gems, e.g. ruby. The stones were not good, being poor in colour and brittle. Some good stones were made and sold, but this process has become obsolete.

**ARTIFICIAL DIAMONDS.** Many experiments were made in the laboratory, for the production of diamonds of which those of Moissan (1893) and of Noble and Crooks (1906) may be briefly mentioned.

**MOISSAN'S EXPERIMENT.** By his experiments, Moissan produced diamonds of microscopic size by dissolving carbon—prepared by the ignition of sugar, in molten iron and suddenly cooling the mass. The melting was done at  $4000^{\circ}\text{C}$ . in an electrical furnace, when the iron melted and was saturated with carbon. The crucible was then suddenly cooled in a waterbath, which resulted in a solid crust and a molten interior. This set up enormous pressures inside and the carbon crystallized as diamond and graphite. The shell was then removed by dissolving it in nitro-hydrochloric acid. The residue consisted of graphite and a few colourless, transparent crystals. Moissan felt convinced that he had produced minute diamond crystals, but it has been recently proved that the crystals obtained were not diamonds. The method of Noble and Crooke consisted in exploding cordite in an iron cylinder for a sufficient period to permit the carbon to be liquefied, and then solidify in the crystal form as diamond. The explosion generated a pressure of 50 tons per square inch and a temperature of  $5100^{\circ}\text{C}$ . Minute crystals were formed, the largest being only 0.5 mm. in length. The success of this experiment has also been questioned. The iron meteorite of the Canyon Diabolo from Arizona is said to have contained minute diamonds. So far no artificial diamonds have been manufactured for commercial purposes.

Hannay's experiments have been successful, and his product proved to be minute diamonds. See a recent paper in the *Mineralogical Magazine*. (*Hannay's Artificial Diamonds*: F. A. Bannister and K. Lonsdale, *Min. Mag.*, Vol. XXVI, No. 181, June 1943, pp. 315-324.) Hannay's minute diamonds were the result of success in his experiments.

**ARTIFICIAL RUBY.** In 1837, Gaudin made artificial rubies by fusing alum at a high temperature with a little chromium as a pigment. In 1847, Edelman made white sapphire by fusing alumina in boric acid. Frenic and Freil made, in 1877, crystal corundum from which small stones could be cut. Frimy and Verneuil manufactured artificial ruby by fusing  $\text{BaF}_2$  and  $\text{Al}_2\text{O}_3$  with a little chromium at red heat. There were also others working on the same lines.

**THE VERNEUIL PROCESS.** In 1902, Verneuil announced to the world that he could manufacture ruby on a commercial scale. Other varieties of corundum and spinel also could be manufactured. The manufactured stones are known as synthetic gems, e.g. synthetic rubies, synthetic sapphire, synthetic spinel. They are akin to the natural stones chemically and physically except for certain features.

The apparatus consists of an inverted oxyhydrogen blowpipe. Purified and finely powdered alumina is kept in receptacles, the bottom being in a fine sieve. The receptacle is tapped by a mechanism, when a small amount of the powder falls into a flame and collects in a support. The fused alumina takes a carrot shape, and is known as a boule or birne, the broader part being uppermost. When the boule reaches 300-400 carats the furnace is closed, allowed to cool for an hour and the boule is removed with suitable tongs. Boules may go even up to 750 carats. If no colouring agent is added, a white sapphire is produced.

These boules have the same atomic structure as corundum or sapphire but no external evidence of crystallization is found. The optic axis is usually inclined to the length of the boule. A hexagonal outline may be visible in cross-section. Boules of 300–400 carats are made in about four hours. One person could attend to about 25 to 60 furnaces at a time, but much technical skill is essential for a successful working of the furnaces. In synthetic ruby about 7% of chromium oxide is used—the darker variety is known as the synthetic ruby, but analysis accounts only for half the chemical added. The colour is uniformly distributed throughout the product. Ruby contains 0.10–1.25 of chromium oxide.

**SYNTHETIC SAPPHIRES.** When 2% of iron oxide and 1% of titanium oxide are added to the alumina under manufacture, synthetic sapphire is the resultant boule. The colour is uniformly distributed—green sapphire is produced when a mixture of the oxides of vanadium and cobalt is used. A number of coloured varieties of synthetic gem corundum could be produced by varying the amounts of the pigmenting agents or by mixing them, and misleading names are given to them, e.g. synthetic topaz, danburite and kunzite. When a mixture of the pigments giving red and blue colours are mixed, a violet sapphire is produced.

✓ **PROPERTIES OF SYNTHETIC RUBIES AND SAPPHIRES.** Chemically and physically the synthetic and natural gems show close similarity. They show also striking similarity in refractive index, birefringence, specific gravity, hardness, crystallization, parting, etc.

Although the synthetic stones are identical with the natural stones in all essential properties, they are different in some features which are of great value in revealing their true nature, i.e. their artificial character. The following are some of them: structure lines, uneven distribution of

colour, presence of gas bubbles, internal cracks, and lack of definite orientation of the cut stones.

*Structural lines.*—Fine structural lines are seen as the material appears to be formed of thin layers prallel to the surface of the boule. These lines may be seen under the microscope in cut stones as well as when cut en c  bochon. The lines are curved, conforming to the shape of the boule. They should be easily distinguished from the zonal distribution of colour in natural stones. The stone should be examined under a microscope immersed in a suitable liquid. Surface striations are also produced in cutting and polishing and also lines due to repeated twinning on natural stones, but they differ from structure lines of synthetic material.

*Gas bubbles.*—Rounded and elongated gas bubbles are also common in the boule. Cloudiness may also be seen, which is considered as due to the collection of gas bubbles in limited areas. It is really due to the faulty handling of the furnace. Gas bubbles are characteristic of synthetic corundum but not of natural corundum, which, however, may contain liquid inclusions; which may also contain gas bubbles. Inclusions of hematite and rutile may also be present in natural corundum. The presence of these certainly indicate natural stones.

*Internal cracks.*—The boules are under great strain and should be handled carefully. But when once the strain is relieved these synthetic stones will not fracture further while being sawed, cut or polished, but due to their brittleness internal cracks may develop. When there are large internal cracks visible easily, they are known as feathers.

*Orientation of cut stones.*—Both synthetic and natural stones are identical as regards composition and physical properties. As the coloured stones show pleochroism, to obtain the deepest colour and the best advantage the table should be cut parallel to the basal pinacoid. This could be best done in natural stones, but not in synthetic stones as

the position of the principal crystal and optical directions in the boules are not constant. The lapidaries also do not orientate them properly to show dichroism on the table. On the other hand, the natural stones are well orientated and hence not dichroic when examined in the same way. This difference is of great help to distinguish artificial from natural cut stones.

The manufacture of synthetic gems on a commercial scale did not begin until after the beginning of the present century. So rubies and sapphires antedating 1900 are in all probability natural. No synthetic star stones have been manufactured. All star rubies and sapphires must be natural stones.

**SYNTHETIC SPINEL.** It is manufactured by the Verneuil process. Beautiful spinels were first produced in 1926, and now synthetic spinels with a variety of colours are on the market. The process is the same as in corundum. Evidence of crystalline structure is present as also cubical cleavage, hardness, specific gravity, etc. Since it is isotropic, it does not show dichroism, which distinguishes it from synthetic or natural corundum and natural zircon and chrysoberyl.

*The value and uses of synthetic gems.*—The natural and synthetic rubies and sapphires are so much alike in all essentials, the artificial stones are in great demand; their prices are only (Rs.6 to Rs.10) \$ 2-3 per carat depending upon the quality, whereas the natural stones of the same quality and weight are much more expensive. A large demand has also arisen for watch jewels in place of natural stones, in physical and scientific apparatus, where hard bearing surfaces are required. They are manufactured in Switzerland, France and Germany with a combined daily output of about a million carats.

**IMITATION GEMS.** They are made mostly of glass, but some are made of plastics and some of bakelite. The



glass used is known as paste or strass—heavy and transparent varieties of flint glass with high refractive indices and dispersion. The composition of the glass is as follows: 300 parts silica, 470 red lead, 163  $K_2CO_3$ , 22 of borax and 1 of white arsenic. The colouring pigments are added. The glass is ground and polished. The glass imitation has the following properties: it has inferior hardness than the gems they simulate and does not scratch ordinary glass, and exposed portions wear off soon; it is isotropic in character, singly refractive and does not show pleochroism. Refractive index depends on the composition—1.50–1.80; specific gravity 2.5–4.0; air bubbles are usually present but not seen in natural stones. Heat conductivity is low in glass imitations; and conchoidal fracture. The first four will decide the glass imitations. Most glass imitations of gems were made in Germany and Czechoslovakia.

**BAKELITE AND OTHER PLASTICS.** Bakelite has found a place amongst imitation gem-stones. It is a condensation product of phenol and formaldehyde. It could be made transparent, opaque or with bright inclusions. It is easily worked and takes a good polish. Imitations of amber and goldstones are common. They are easily moulded and worked and also possess wearing qualities.

**DOUBLETES AND TRIPLETS.** True doublets consist of two sections of genuine material to make a larger stone, which gives a larger value than that of 2 smaller stones. Its nature could be detected by immersing it in a liquid, whose refractive index is equal to that of the stone or soaking it in alcohol or chloroform in which the cement is dissolved.

**THE FALSE DOUBLET.** It has a genuine crown and pavilion of inferior stone or glass. A thin slice of ruby or garnet may be matched with coloured glass. It could be detected by the methods already mentioned. Triplets have been used to imitate the emerald. The top portion

consists of glass and the lower portion some mineral or glass separated by a piece of foil, a coloured layer or a thin plate of coloured mineral to give the stone a desirable tint. By immersing in liquids with proper refractive index, the deception could be easily detected.

## CHAPTER X

### PRECIOUS METALS FOR MOUNTING GEM-STONES

GOLD, platinum and silver are widely used for mounting gems, but gold and platinum are the more important as they do not tarnish as silver. As pure gold is very soft and malleable, for a durable mounting, it is usually alloyed with other metals to increase its hardness. The gold content of the alloy is expressed in carats or  $1/24$ th parts. Usually, 18 carat gold containing 18 parts gold and 6 parts alloy has good wearing qualities. The usual alloys are:—yellow gold: 18 parts gold, 3 parts silver, and 3 parts copper by weight (darker shades are obtained by increasing copper content); white gold: 75% gold, 17% nickel, 2·5% copper, and 5·5% zinc (this alloy is harder and more durable than platinum and iridium and serves as a substitute); green gold: 75% gold, 22·5% silver, 1·5% nickel and 1% copper (it is also used for mounting purposes).

Pure platinum is soft and flexible and has to be alloyed with a metal to give necessary hardness and rigidity. Alloyed with 10% iridium, hardness of platinum is considerably increased. This is also suitable for mounting gems.

Silver is not used for mounting of gems.

## PART II

### CHAPTER XI

#### DIAMOND

##### I. INTRODUCTION

DIAMOND, the most precious of gem-stones, has been known from ancient times in Indian and other eastern countries, known as Vajra = hirak (Sanskrit); both the terms are used in the different Indian vernaculars. It is, commercially, also the most important gem-stone, because it is the hardest, the most imperishable and the most brilliant of minerals. Attempts at manufacturing diamonds never proved a success and are only of scientific interest. It has the simplest composition. It is crystallized carbon, another form of which is graphite. Diamond has maintained its eminence as the most valuable of gem-stones, but it is also becoming very valuable in industry which uses all the by-product and non-precious diamonds.

The word diamond has been derived from the Greek and Latin terms, 'Adamas' (16 A.D.) whose original meaning was invincible. By usage the following changes took place as 'adamant', 'diamant' and 'diamond'. Pliny (100 A.D.) speaks of the rarity of the stones. The Romans knew of it when it was introduced from India.

The discovery of diamonds in India predates the birth of Christ by several millennia. Kautilya's *Arthasāstra*, a work of third century B.C. refers to six kinds of diamonds from as many mines. It was about the fourteenth century that the cutting processes were introduced from India to Europe, and the diamond did not come to its eminence till the fifteenth century. Till the middle ages, ruby, peridot and pearl were considered more precious. Indian lapidaries were the first to realize that diamond could be

cut with its own powder, and that the removal of the skin in a natural stone made a great change in the stone.

In the fifteenth century, it became very popular and during the next two centuries, India had a flourishing diamond trade. Alas! the discovery of the rich Brazilian fields in 1725 dealt a death blow to the diamond fields of India. In the latter half of the nineteenth century, the discovery of the rich African fields proved also a disaster to the Brazilian fields. Nevertheless, India still holds the reputation for having produced some of the finest and largest diamonds. South Africa now produces 95% of the world's diamonds, whereas the Indian production is almost negligible. The world's aggregate diamond production till about 1937 has been estimated at about 279 million carats or roughly about 61.5 tons. Now the world's average annual production has exceeded 10 million carats. The production was first from gravels, then from pipe mines, which have been in turn superseded by the alluvial deposits as the chief producers.

## II. PHYSICAL PROPERTIES, ETC.

Diamond crystallizes in the cubic system, the common forms being octahedron, rhombic dodecahedron, tetrakis-hexahedron and spinel twins. The crystals are usually small, but larger crystals may also occasionally be found. The Indian stones are usually octahedrons, whereas the Brazilian stones are dodecahedrons. The Panna stones are hexakis-octahedron, tetrakis-hexahedron and hexakis-tetrahedron. The most common form is the octahedron, but the edges are not sharp and tend to curvatures near the corners, giving a rounded outline to the whole. Corners may not be present in some. In dodecahedrons the edges and corners are much sharper than in octahedron. The cube faces may be present as replacement forms in better diamonds. Irregular crystals are more numerous than those of good shape.

In alluvial stones, the original shape is not present due to wear and tear. The mine diamonds are often beautiful with triangular depressions or 'trigons' whose angles point to the octahedral edges. This enables the determination of orientation in broken crystals. The trigons are 'etched figures'. In dodecahedrons, striations parallel to the longer diagonals of the rhombs are seen.

*Twinning.*—Octahedral and dodecahedral twins are common. The spinel twin is also called the 'macle'. Macles are rounded like simple crystals. Illusory twinning, 'trigons', are depressions. Elevations rising from a triangular base on the octahedral faces are also oriented conformably with the face. These elevations tend to arrange themselves symmetrically about the coigns of the crystal. They are nearly colourless and lose a great deal of weight in cutting.

*Specific gravity.*—The specific gravity of diamond is 3.5-3.6. Pure diamond has 3.53, the black variety 3.45-3.52 and bort 3.6. Hardness is 10 on the Moh's scale of hardness. It is the hardest mineral known, but it does not mean that it is twice as hard as apatite. In a scale representing relative hardness, the value for diamond would be 100 rather than 10. Diamonds from various areas are found to have varying hardness. The diamonds from Borneo and Australia are said to be harder than those from Kimberley. Perhaps some impurity might contribute to increased hardness. Hardness must not be confused with toughness, as diamonds are brittle and easily chipped.

It has also been found that hardness in diamonds varies with the different crystal faces and also with the direction of the faces. This fact is known to diamond cutters, as also the following: (a) faces parallel to the cube are easy to polish, as they are parallel to two crystal axes; (b) rhombic dodecahedral faces are parallel to one crystal axis, and hence less easy to polish them than the faces parallel to the cube; and (c) the octahedral faces being

equally inclined to three crystal axes and not being parallel to any crystal axis are the most difficult to polish. The change in hardness from one face to another or from one direction to another is not abrupt but gradual.

Cleavage is parallel to the octahedral face (111) and the mineral breaks along the four perfect cleavages parallel to the face of the octahedron. Dodecahedral cleavage is imperfect. Fracture is irregular and may vary also from conchoidal to splintery. Colour may vary from yellow, brown, grey and black. Each of them may have several grades. The bort belongs to the grey species and occurs in round and shapeless lumps and fragments. It has crystalline structure. The following are the varieties of diamond: (1) diamond proper, (2) bort or bortz, (3) ballas, and (4) carbonado.

*Optical properties.*—The crystals may be clear and transparent with a brilliant lustre on the surface, but may be also translucent and opaque. The transparent stones are valued as gems. The lustre is adamantine, but an uncut diamond may be dull or greasy. Carbonado may have a dull lustre. The full properties of diamond, i.e. brilliancy, fire and play of colours, for which the diamond is highly valued as a gem, are brought out by cutting and polishing. Diamonds cut for jewellery are known as 'brilliants'. These valuable qualities of diamond are due to its optical characters, e.g. refractive index 2.402 for red and 2.465 for violet and their difference 0.063 the dispersion. It is singly refractive or isotropic, but anomalous double refraction may be noted due to internal strains. Double refraction may also be noted surrounding enclosures or cracks. In respect of play of colours (prismatic) the Indian stones rank highest, followed by Brazilian and the Cape diamonds.

Inclusions of graphite are most common. Other minerals found as inclusions are ilmenite, chromite, magnetite and hematite. Garnet also occurs as rounded grains or frequent

inclusions. It may enclose or be enclosed by diamond. Bubbles of liquid  $\text{CO}_2$  are also found. Diamond also occurs as an inclusion in diamond. In composition it is pure carbon. Diamond, graphite and charcoal are allotropic forms of the same element carbon. Spontaneous explosion of diamonds has been reported due perhaps to accumulated strains. Phosphorescence is also common. It burns in air at  $850^\circ\text{C}$ . It is insoluble in acids and alkalis. It becomes positively electrified by friction and is a non-conductor of electricity. When exposed to ultraviolet rays an electric current is produced through some diamonds. After prolonged exposure to radium a colourless diamond becomes green. Bort is a good conductor. It is also a good conductor of heat. It feels colder to touch than glass and imitation stones and has a greasy feel.

*Fluorescence.*—Under ultraviolet rays, some colourless diamonds show a cornflower blue glow and while greenish diamonds, show a greenish yellow glow. Diamond is much more transparent to X-rays than other minerals and much more so than glass imitations. The luminescence has been ascribed to the inclusions of some unknown hydrocarbon minerals. Dake arrived at the following conclusions: (1) non-fluorescent diamonds carried the least amount of metallic inclusions and may be considered the purest form of diamond, (2) the bort which fluoresced a strong blue contained the greatest amount of metallic elements, and (3) diamonds which fluoresced in different colours contain different proportions of various metallic elements. The metallic elements found include chromium, iron, calcium, aluminium and manganese. The more common metallic element was chromium.

In recent years, the crystal structure and optical characters of diamond have been studied intensively by Sir C. V. Raman and his co-workers at the Indian Institute of Science, Bangalore. According to spectroscopic studies

of his co-workers, it has been found that luminescence is not due to extraneous impurities, but is a property of diamond itself. This indication is further strengthened by the definite correlation which is found between luminescence and other properties, which differentiate the allotropic modifications of diamond. Fractured edges of cleavage plates of diamond luminesce far more strongly than the polished faces of interior of the crystal. So the inference is that luminescence is excited by purely physical cause, namely a disturbance of the regularity of the crystal structure. The variations in intensity of the luminescence may be explained as due to variation in the number and extent of such irregularities within the diamond. It is also evident that an intimate interpenetration of positive and negative tetrahedra in diamonds of lower symmetry would constitute a disturbance in the regularity of crystal structure.

\* 'It has been found unnecessary to postulate the presence of extraneous impurities in the diamond, and if such impurities were the cause of luminescence, it would be difficult to understand why diamonds having the higher type of symmetry do not exhibit luminescence to anything like the same extent. On our present views, the latter fact finds a natural explanation in the circumstance that such interpenetration does not exist in the octahedral variety of diamond. The chemical or impurity theory is also discredited by the observation that strongly blue luminescent diamonds are often of highest quality in respect of transparency and freedom from colour.'

*Size of diamonds.*—The average size of diamonds obtained in different countries varies considerably. When India and Brazil were the only countries producing diamond, stones of more than 20 carats in weight were a rarity, and

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\* Raman, Sir C. V., and others. The structure and properties of diamonds, *Current Science*, Vol. XII, No. 1, pp. 33-42 (Supplement), 1943.



even such stones were found only once in two or three years. Stones exceeding 100 carats in weight were seldom found. The 'Star of the South' weighed in the rough 254.5 carats, though considered a large stone. There were greater chances of finding larger diamonds in the Indian deposits and a number of stones exceeding 100 carats in weight were obtained. As most of the stones are known only in the cut condition, their original weight could only be estimated. Of the stones known in their rough condition 'the Regent' in the French Crown jewels is the heaviest; its weight before cutting was 410 carats and when cut yielded a beautiful brilliant of 136.875 carats. The 'Great Moghul' is supposed to have weighed originally 767.5 carats.

The South African fields yielded stones of up to 150 carats in weight more frequently, and some were of several hundred carats. The largest stone discovered was at the Cape in 1893, which weighed 971.75 carats. On 13th August, 1938, in the Santo Antonio river a pure blue-white diamond weighing 726.6 carats was obtained and named the Vargas diamond in honour of the President of Brazil. It was cut in the U.S.A. and divided into twenty-three stones.

### III. GENESIS

Diamond has been found as a constituent of the earth's crust, e.g. occurs in the Kimberlite pipes of South Africa, the matrix being an altered peridotite; but it has also been found in extra-terrestrial bodies as meteorites. One such recent discovery is that of Canon Diabolo of Arizona, where a meteorite that fell recently contained diamonds as was proved by X-ray. But diamonds have been found mostly in secondary deposits, e.g. sands and gravels, which are often changed to firm conglomerates.

The discovery of the diamonds in the 'dry diggings' of South Africa and their development into deep mines yielded a wealth of evidence on the genesis of the diamond.

Two opposing theories were proposed on the origin of the diamond: (1) the diamond crystals had formed in the original magma before eruption, i.e. before the Kimberlite pipes were forced up, and (2) the crystals were formed after eruption (the carbon being derived from the Karoo shales) —the latter theory is considered the more probable due to the inclusions.

Sutton discusses the genesis of diamonds comprehensively. After dealing with all the prevailing views, he comes to the following conclusions:—

1. Diamonds formed as a late constituent on eclogite margins.
2. It separated from the magma first as a plastic crystal, becoming solid later on.
3. It grew by the successive superimposition, mostly continuous though sometimes intermittent, of plastic shells either on the plastic or on the solid core.
4. Its form and habit were determined by: (i) the octahedral spacings of the atoms, (ii) the tetrahedral spacing of the same, (iii) shrinkage on solidification, (iv) its environment, i.e. the chemical composition of the mother liquor or whether it grew on or beneath the eclogite surface of the matrix.
5. There is no evidence to prove that it has suffered resorption. The internal structure is governed by the process indicated in the third clause. By the first clause the temperature of crystallization must have been relatively low though covering probably a considerable range dependent on the richness of its solution.

The genesis of the diamond is intimately associated with the origin of the Kimberlite, which has been discussed at length by Alpheus F. Williams. According to him,

diamond crystallized mostly in a residual magma before its ascent into the pipes, and this residual magma rose and intermixed with the semiplastic magma already filling the pipes.

#### IV. DISTRIBUTION IN INDIA, BURMA AND CEYLON

India was the first to produce the World's finest diamonds, which continued till the second decade of the eighteenth century. During the sixteenth and seventeenth centuries, there was the maximum production of several hundreds of thousands of carats per annum. The output now is very small and insignificant. Golconda was the most famous for the largest and best stones. In fact Golconda formed the trade centre and not the mine centre. The famous diamonds as the Koh-i-noor and the Pitt had their origin in the Kistna district.

Tavernier, a French traveller, made a number of voyages in the seventeenth century, visited all the diamond mines and did considerable trade in precious stones. He was the first to give ideas of these mines to the western countries. According to him, most of the stones had their origin in the Kollur group, in the Guntur district in South India, where he found 65,000 workers in 1645. The mines had started work a hundred years previously. A full description of the Indian diamond fields is given by V. Ball. Since then there have been several papers which contain descriptions of the ancient and now defunct diamond fields of India. The places which were the most productive in the past fall in 3 groups, each in association with the old unfossiliferous rocks of pre-Cambrian age, known as the Purana group comprising the Cuddapah and Karnul formations in South India and the Vindhyan system in North India.

##### *South India*

The following districts were famous for diamond localities: e.g. Cuddapah, Anantapur, Bellary, Kurnool,

Kistna and Godavari. Loose stones are occasionally picked up from the ground. The stones have been obtained from the alluvium and from workings in the Banganapalli stage of the Kurnool series of strata. No official returns of production are available, but a number of small and at times valuable diamonds have been reported as picked up after showers of rain round Wajrakarur in the Anantapur district. Some years ago a stone weighing 60 carats was found and was expected to sell at a lakh of rupees.

During 1910-12, Mr. A. Ghose prospected the Virayapalle area in the Karnul district. He found that the diamond bearing conglomerate was found to vary in thickness from 3 in. to 2 ft. Sixteen cubic feet of the rock were found to yield  $\frac{1}{8}$  to  $\frac{1}{2}$  a carat of diamond. The stones were perfect crystals of fine quality and free from flaws. Since then there is no information on output or mining in Madras.

*Anantapur district.*—There is a volcanic neck, filled with a decomposed basic rock at Wajrakarur ( $15^{\circ} 2' : 77^{\circ} 27'$ ) similar to the matrix of diamonds at Kimberley, but no stones have been obtained from the rocks of the pipe. It is a highly altered plagioclase-augite rock, not similar to the blue ground. A stone valued at £10,000 was once obtained from the neighbourhood. In 1861 a diamond weighing  $67\frac{3}{8}$  carats was cut by Messrs. P. Orr & Sons, Madras, to  $24\frac{5}{8}$  carats.

Diamonds were regularly picked up year by year in the fields surrounding the pipe to a distance of about 3-4 miles from it. It is impossible to estimate the value of the finds but direct attention to the pipe itself has so evidently proved unprofitable. Sir C. S. Fox, who visited the area in 1930 is of the opinion that the diamonds of the fields near Wajrakarur have weathered out of the pipe rock. According to him the pipe rock though agglomeratic in constitution is more clearly allied to the doleritic intrusions of the Lower Cuddapah than to the Kimberlites of South Africa.

*Cuddapah district.*—Diamonds were obtained from a gravel 6 ft. deep below the surface: (1) Chennur ( $14^{\circ} 34' : 78^{\circ} 52'$ ). Two good stones are said to have come from here. The mines are not working. (2) Kanuparty or Kondapetta ( $14^{\circ} 33' 30'' : 78^{\circ} 52' 30''$ ) is situated opposite to Chennur on the Pennar river. The area covers one square mile and is reported to have produced large stones, but work is not productive these days. The diamond was found in a gravel composed of pebbles, quartz, chert and jasper lying beneath from 4 to 12 ft. of black cotton soil. (3) Ovalampalli or Woblapalli is close to Kanuparty. This area is reported to have produced some valuable stones.

*Godavari district.*—Bhadrachalam ( $17^{\circ} 40' : 80^{\circ} 57'$ ). Stones were obtained from river bed near the town.

*Guntur district.*—(1) Kollur ( $16^{\circ} 43' : 80^{\circ} 5'$ ). Tavernier visited this place in 1645, found it very prosperous with 60,000 persons engaged in operations. The mines were situated on the right bank of the Kistna between the river and a range of mountains. The workings were 12–14 ft. deep and not below the level of the subsoil water. The Great Moghul diamond is said to have been found here. After cutting it was known as the Koh-i-noor. This area was exhausted by 1677. (2) Madagula ( $16^{\circ} 30' : 70^{\circ} 38'$ ) was very productive, but due to unhealthiness it had to be abandoned. (3) Malavaram ( $16^{\circ} 36' : 79^{\circ} 31' 30''$ ) lies between Kollur and Ramulkota. The stones here were brittle.

*Kistna district.*—The localities are situated between Bezwada and the Nizam's territory, a detailed account of which is given in the Kistna District Manual. Workings are located in the alluvial area, the gems being found in the sub-recent gravels, either derived from Kurnool series or the Golapilly sandstone: (1) *Golapilly* ( $16^{\circ} 43' : 80^{\circ} 55'$ ) with Malavilly or Maleli. Perhaps the gems were obtained from lateritic gravels and alluvial gravels also. (2) *Malavilly*—the Golapilly and overlying Rajahmundry

sandstones were searched for stones. (3) *Partial* ( $16^{\circ} 39' : 80^{\circ} 28'$ ). The diamonds were very small. In 1890, the Hyderabad Deccan Co. attempted to open the mines with modern machinery. 3,444 stones weighing  $2,085\frac{7}{8}$  carats were obtained. Work was stopped in 1894 as it was not paying. (4) *Ustapilly* ( $16^{\circ} 42' : 80^{\circ} 13'$ ) with Kodavattukallu was like Partial which was supposed to have produced several bullock-loads of diamonds.

*Kurnool district.*—Many old workings are found in this district, which has given its name to the formation containing the band of conglomerate from which many diamonds were obtained in South India. There are 24 localities in this district, but the following are the more important: (1) *Banganapalli* ( $15^{\circ} 19' : 78^{\circ} 17'$ ). The diamond-bearing layer forms the basement bed of a band of quartzite 20–30 ft. thick, forming the lowest member of the series. This band of quartzite is exposed over a large area, but the productive layer consists of shaly breccia, conglomerate or pebbly clay. The latter occurs in seams of 6–8 inches in thickness. The diamonds are flawed and very small. (2) *Dhoni* ( $15^{\circ} 23' 30'' : 77^{\circ} 56'$ ). Stones obtained were well shaped and of weak water. (3) *Lanjapalur* ( $15^{\circ} 45' 30'' : 78^{\circ} 4'$ ). Stones obtained were well shaped and of good water. (4) *Ramulkota* ( $15^{\circ} 34' : 78^{\circ} 3' 30''$ ). Tavernier's Raolkonda—small stones of excellent water were found in sand or earth filling narrow veins in the rocks. (5) *Virayapalli* was recently prospected by Mr. A. Ghose.

#### *Second group of occurrences*

These occurrences are mostly in the Mahanadi valley. The stones were found in Sambalpur and Chanda districts in alluvium; the Karnuls and Vindhya occur in this area, but no diamonds have been found in them. The stones were obtained from a red, gravelly earth and were collected from the bed of the Ib river (Hebe), at Hira

Khund, 4 miles below the mouth of the Ib river and a few miles above Sambalpur. According to V. Ball the stones were only to be found in the bed of the Mahanadi itself. Some stones were obtained between 1804 and 1918. Twenty stones were obtained of which the largest weighed 672 grains.

### *Third group of occurrences*

*Central India Agency.*—In this area the diamond-bearing localities occupy a tract 60 miles long by 10 miles wide with the Vindhyan conglomerates near Panna as the centre. The diamond mining industry still persists in this area on a small scale, both in Vindhyan conglomerate and in alluvium. Diamond is found in the following states: Panna, Char-khari, Bijawar, Ajaigarh, Kothi, Pathar, Kachar, Baramunda and Chobepur. The following scale gives the position of the diamond-bearing strata with reference to the Vindhyan formations:—

Upper Vindhya	{	Bhander series.	
		_____	D. horizon.
		Rewa series.	
		_____	D. horizon.
		Kaimur series.	

Near Panna, there is a band of conglomerate between the Upper Kaimur sandstone and Panna shales locally known as '*Mudda*', the diamond-bearing stratum. It is about 2 ft. in thickness, and is not a continuous bed. Further east, near Itwa the diamond-bearing conglomerate does not rest directly on the Kaimur sandstone, but is separated from it by a 20–25 ft. bed of shale and limestone. Another diamond conglomerate occurs above the Rewa sandstone and below the Bhander series.

The diamonds and the pebbles of the conglomerate are derived from older rocks, and the origin of the gem is still unknown. The pebbles in the conglomerate consist of jasper and vein quartz. The stones are found embedded in the conglomerates and also from the neighbouring

detritus derived from the disintegration of the Vindhyan beds. The workings are also distributed accordingly—some on removing the undisturbed conglomerate and others to recover stones included in the more recently distributed detritus. When the conglomerate is covered by younger Vindhyan rocks, it is reached by workings, which are often, but not always, deep. Such workings are known as 'direct workings'. In some places the overlying rocks have been removed by weathering agents, and the conglomerate thus exposed affords shallow workings. In the case of conglomerate removed and deposited in river valleys, the stones are obtained by superficial, shallow and deep workings, which come under alluvial workings.

The following are the mining areas at present working: (1) *Shahidan* area forms the best centre in the Panna State, and has been working regularly since 1916. The size and quality of stones are better than in other mines. Due to unsystematic working, the mines present a confusing spectacle. Water often runs from old workings, rush into newer ones and spoil the mines. (2) *Panna group*—*Ranipur* and *Bhavanipur*—the latter has been working from 1916 to the present day. It occurs in redistributed material of the *mudda*. Undecomposed material may also be present. (3) *Baghri* group of mines—The *Itwa* field—it is next in importance to the *Shahidan* diamond field, and is 13 miles N.E. of Panna. Workings are now in alluvium, but many years ago mining was in a regular conglomerate bed occurring below a sandstone. At a depth of 20–40 ft. from the surface a diamondiferous gravel bed is also present. (4) *Majgarwan agglomerate tuff*. These mines lie to the west and southwest of Panna. The diamond occurs in a green mud and it is said that diamonds became more abundant as a shaft descends. The rock, on careful examination, has been found to be an agglomeratic tuff. The greenish tuff occurs at a depth of 105 ft. from the surface in the particular part where the borehole was



put down. The Majgawan deposit was a true volcanic pipe, the tuff very much resembling the Kimberley ground.

No diamonds have ever been found either in Ceylon or in Burma.

## V. PREPARATION, MINING, ETC.

The first diamonds in most countries were discovered in secondary deposits, i.e. in the sands and gravels of stream deposits which are known as 'river diggings'. The separation of diamonds from the associated sands was done by washing as in the case of gold.

*Diamond mining in South India.*—There is ample and reliable evidence to prove that the mines were enormously rich and their wealth proverbial, which reached Europe through the writings of Marco Polo in the thirteenth century. (1275–1295). The mines were known from the sixth century. They are known to have been leased in the seventeenth century by the kings of Golconda and Vijayanagar on a royalty system, with one of the strictest conditions that stones above 20 mangalins (about 25 carats) were sent to the 'Raya' for his own personal use.

In 1662, William Methold, Sir Andreas Soccy and Sir Adolph Thomson visited the diamond mines from Masulipatam. According to them, the king received 300,000 pagodas (£120,000) for the mines from the contractor, all the stones above ten carats being the king's property. The Moghuls and their Viceroys 'squeezed' the mines to such an extent that many were forced to stop working.

Between the years 1636 and 1662 Tavernier made 6 voyages for collecting gems and trading, and visited Ramallakota and Ganikollur. At Ramallakota he witnessed the diamond mining from an old pebble conglomerate at the base of the Karnul series of rocks. At Kollur he studied the methods employed by the Indians. When dealing with alluvial deposits, he dealt also with the mining methods, etc. According to him a diamond with a

green crust was bought always without any hesitation, as it was certain to be always of the first water.

Mr. Cholmley resided in Golconda and prior to 1679 bought diamonds for the East India Co. from Golapalle and Mullvale. The mines were at the zenith of their production and fame during the sixteenth and the seventeenth centuries. Then they declined gradually, and in the nineteenth century, these very mines which had produced gems of fabulous values were farmed out for a paltry sum of 8 annas per month.

*Diamond mines of Central India.*—The Panna mines of Shahidan, Majgawan, Itwa and Udesna were visited by Capt. Franklin, Rousselet, Medlicott, and Capt. Pogson many years ago. In olden times mining was extensive and very profitable. In recent times work is done only in Shahidan and Itwa. During Emperor Akbar's time it produced eight lakhs of rupees worth of stones. These mines were idle in the seventeenth century, but in the eighteenth century there was again mining activity. The present income is very small to the State. The discovery of the South African fields delivered a death blow to Panna.

*Diamond fields in other continents.*—*Brazil.* It is believed that diamonds were first discovered in Brazil in 1670 in the recent gravels in gold washings, but were not definitely identified till 1721. The diamond areas are in the provinces of Minas Geraes and Bahia. The diamond deposits are secondary and diamond occurs in association with gold, cyanite, tourmaline, garnet, etc. They also occur on plateau gravels whereas in India diamonds occur with pebbles of jasper and quartz. Diamond mining in Brazil is carried on by primitive methods. Brazilian deposits had their heyday between 1721 and 1870, but their present output is small.

*Africa.*—In 1870, diamonds were discovered in primary deposits or 'dry diggings' at Kimberley, in circular or

elliptical area 200-300 yards across. These areas were divided into 30 ft. squares or claims. Paths were left between the claims to the diggings. Stones were first recovered from the weathered yellow ground. Gradually the workings deepened, the roadways became steep-sided ridges leading often to landslides, when working became more and more costly. This led in 1888 to a consolidation of all the diamond mining properties in the Kimberley district, largely through the efforts of Cecil J. Rhodes. The resulting organization came to be known as the De Beer's Consolidated Mines, Ltd. The De Beer's mines have an area of 40 acres, in cross-section and had a depth of 1,500 ft. These pipes are filled with a porphyritic, ultra-basic lava; the pipes occur in clusters and mining has revealed that they have been derived from a common fissure at depth and the pipes are located in lines of fissure. The material of the pipe has been divided into the 'yellow ground', the weathered and oxidized zone of kimberlite breccia, and the 'blue ground', the unweathered part running to 5,000 ft. depth, which weathers easily when exposed; and the 'hardebank'—compact and well preserved kimberlite. Conditions have been found to vary in pipes due to difference in origin. Different pipes also produced diamonds of different nature. All these pipe mines (De Beer's) were closed down owing to market conditions in 1932, after they had produced diamonds worth £90 millions. These mines started as open pits and passed on at depth into modern underground mining by means of shafts and drifts. The Kimberley mine was worked to a depth of 3,600 ft. and most of the work was done by natives. All mines in South Africa were shut down in 1941 and only maintenance work was done. It has been decided to abandon the old De Beer's mine which had not been worked since 1908. Pumping was discontinued on May 16th, 1941, after clearing all equipment from underground.

## REOPENING OF SOUTH AFRICAN MINES

It was decided to reopen two mines of the De Beer's group, the Premier Mine, Pretoria and the New Jagersfontein. Dewatering is going on and they are expected to produce in 1948 at the earliest. Belgian Congo is the World's largest producer, but 90% of it is industrial material.

### TREATMENT OF ORE

In the early years the blue ground or the ore from the mine was left in open fields called depositing floors for weathering. The rock gradually softened and became friable. The larger pieces were broken by sledge hammers. The material thus broken up was taken to the crushing and washing plants for concentration. This practice is no longer in vogue. The ore, nowadays is directly crushed and washed as soon as it is received from the mines.

The following processes are employed to win the diamond from the ore:—

- (a) Crushing and washing; (b) Jigging; (c) Greasing or automatic sorting; and (d) Cleaning and evaluating.

(a) *Crushing and washing*.—The crushed material is passed into the washing machines, consisting of large pans or shallow tanks about 14 ft. in diameter. Water flows into these pans, the mixture is well stirred, which causes a mechanical separation of the heavier and lighter material and also eliminates 99% of the lighter material.

(b) *Jigging*.—The concentrates from washing are passed through screen and sized, and then passed on to the jigs and pulsators, where further concentration is effected by gravity. The concentrates from the jigs were first hand sorted, but now the greaser has taken its place.

(c) *Greasing or automatic sorting*.—This method came into force in 1896. It was found that grease sticks most tenaciously to diamond than to any other mineral in the

concentrate. The grease table is a sloping table coated with thick grease. The concentrates from the jigs pass up in the greaser at one end and everything passes off over the grease at the other end except the diamond, pieces of metallic minerals and metals. This method has been found to be very efficient. They are also enclosed to prevent theft.

(d) At intervals the grease is removed to recover the diamonds from the automatic sorters. After suitable treatment, the grease is used again. The stones are cleaned by boiling in acids and alkalies. The stones are sorted and weighed and made into packets ready for the market.

The Premier is the largest known diamond mine with a surface area of 80 acres. The pipe mines used to supply most of the world's production but latterly the alluvial deposits became more important. But recently all the deep mines have been closed, and now the production is mostly from alluvial deposits. The most important alluvial deposits of diamond are located in the Belgian Congo, Gold Coast, Sierra Leone, Angola, Union of South Africa and South-West Africa. Other areas include Brazil, British Guiana, Borneo and India.

In India, Central India is the only place where the diamond mining industry is extant. The methods of diamond mining now at Panna are just as primitive as those described by the early observers. The methods of winning the diamond from the ore are also primitive. The workings consist of three kinds: (i) deep workings, (ii) shallow workings, and (iii) alluvial workings. The workings extend from 25 ft. to about 70 ft. The diamond occurs in a friable conglomerate 5-12 ft. below the surface, and in alluvial workings there is no trace of conglomerate. In one area at Majgawan an agglomeratic tuff was found resembling very much the Kimberley ground (cf. Wajrakarur, mentioned *ante*).

Every year the miners sink a few pits according to their purse and requirements as there are no restrictions about the size or the site of the pits sunk. The pits are usually 15-40 ft. in diameter. The miner tries to remove as much of the diamond conglomerate as possible with the least outlay. The work is started suitably so as to expose the diamond conglomerate in April or May when the water level is low. The conglomerate is very tough and hard. A fire is lit over it with logs of wood. Due to expansion cracks are formed in the rock, which is then opened by wedges. Water is usually pumped by primitive methods, but now centrifugal pumps are also employed. Men, women and children form the labour, carrying the ore in small baskets. After removing the conglomerate, galleries are driven in different directions to remove as much of the ore as possible. The ore is stacked in heaps till the onset of monsoon, when the crushing and washing operations start. The ore is broken up to desired size, and the crushed material is washed in regular pits dug in the soil and lined with slabs of sandstone. The washed material is then spread on a clean and smooth piece of ground. After drying the stones are carefully picked.

The stones obtained may be either waterworn or in crystals which show the properties of the diamond to a certain extent. The properties of the diamond are enhanced by cutting and polishing. This subject has already been dealt with in detail. The 'brilliant' has been found to be the most expensive, modern and the best form of cutting, and is said to be the crowning achievement of the art of cutting.

## VI. SPECIFICATIONS AND VALUATION

Diamonds are divided into two broad classes, i.e. (a) Precious, and (b) Non-precious or Industrial stones. In a treatise on gem materials we are mostly concerned with the 'precious' category. In ancient India there was a

fourfold division of diamonds according to their properties, viz. Brahmin, Kshatriya, Vaisya and Sudra, each class of stones having its own qualities and properties, which are dealt with in detail in *Manimala*, pp. 101-107. The modern classification of diamond is based on their physical properties. The most important physical properties are transparency, clearness and freedom from faults or defects. The transparent gem diamonds are classified as of first, second or third water and the value depends very much on it. First water stones are the best stones, which are perfectly colourless, transparent and water clear as also free from any fault or blemish or tinge of colour. Such stones fetch the highest prices. Second water stones must also be colourless, but may contain slight defects or a tinge of colour. Third water stones have distinct faults or undesirable tints.

There are several other factors governing the value of gem diamonds, e.g.:—

- (i) The larger the stone, the greater is its value. Owing to the comparative scarcity of large stones, the progression in price is greater than in size. In the case of exceptionally large stones, there is no rule and the price is solely governed by the special circumstances.
- (ii) The value of the diamond is also governed by its cutting. The 'brilliant' cut is the costliest and it has been mentioned that a perfect one carat brilliant fetches four times the value of the rough stone.
- (iii) Form is another governing factor. Octahedrons and dodecahedrons could be cut into brilliants more easily and command a higher price. A twinned crystal is not to be preferred.
- (iv) The value of the diamond also depends on the clearness and purity of its colour. Transparency and clearness are of utmost importance.

The colour that is much appreciated is a bluish white. Other colours of diamonds are blue, grey, red and yellow. Coloured stones are also treated as fancy stones. Brown and black stones are not preferred at all.

- (v) The value of a stone also depends on freedom from flaws, which depreciate it very much. If the flaws are serious or numerous, the stone is not considered worth cutting and passes for bort.

In India flaws in diamonds are taken very seriously as they are supposed to have evil propensities likely to affect the wearer or owner seriously. The flaws are known as 'Rekha', 'Vindhu', 'Kalanka', 'Kakapada' and 'Trasa' each of which is supposed to bring serious trouble and sufferings to the owner and wearer. All these points are dealt with in great detail in *Manimala*. 'Rekha' is a stripe which renders the wearer apprehensive of snake bites. 'Vindhu' is a blood-red circular spot and a vindhu marked stone is considered inimical to life and property. The stripe in a diamond if it resembles a bird's wing is termed 'cheda', which brings about loss of friends. 'Kakapada' is like the claw of a crow and dirty. Death and ruin are near the man who wears a diamond with kakapada. 'Trasa' is a mark which shows an apparent brokenness in the stone. It always gives rise to fear. It is also said that a diamond, whose face is cracked, whose top is rent, and whose centre is full of dirt can even deprive Indra of his highest heaven.

*Grading of diamonds according to colour.*—There is no hard and fast standard for reference. The market usually depends on the trained human eye and judgment for the colour grading. If fancy stones are left out, there are only stones in the usual trade for consideration. The finest of them are known as the snow-white, 'Rivers' and 'Jaeger' the latter has a bluish tint. Next come the 'Blue Wesseltons' or top 'Wesseltons'. These lack something when put beside the 'River' or 'Jaeger'. Wesseltons





were found more often, the rate of increase by the square fell down.

The following stones were put in the London market by the De Beer's group of mines by the diamond merchant syndicate: (a) blue-white, (b) white, (c) silvery cape, (d) cape, (e) fine byewater, (f) byewater, (g) fine light brown, (h) light brown, (i) brown, (j) dark brown. Byewaters and byes are stones tinged with yellow.

The following prices were also quoted:—

	Blue-white.	Byewater.
	£	£
5 carat stones	.. 40-60	20-25
1 „ „	.. 30-40	10-15
$\frac{1}{2}$ „ „	.. 20-25	8-12
$\frac{1}{4}$ „ „	.. 15-18	6-10
Melee (smaller than $\frac{1}{4}$ carat)	12-15	5-8

At present there is no law of value per diamond, and much depends on what the retail buyer is prepared to pay. But the prevailing prices appeared to work to the following formula:—

$$(n-1) D + P = R,$$

where  $D$  is the approximate difference in price between crystals of one and two carats.  $n$  = weight,  $P$  = price of stone of one carat,  $R$  = total value.

In 1941, the Diamond Trading Co. sold rough valued at £7½ millions. The U.S.A. bought 'American Qualities' (i.e. relatively fine and large stones) as were available and some fine small rough, but the increase in sales was largely due to purchases of industrial stones by the U.S. Government, Russia and American brokers. The Diamond Trading Co. has offices in London, Kimberley and also opened a branch in Bermudas to deal with the cutters and brokers in U.S.A.

*Recent trends in prices.*—Prices of rough diamonds increased by 10 to 15 per cent and further rise was expected

in 1942. Prices of large cut stones rose by 10 to 20 per cent than in pre-war times, but the prices of small variety have become double or quadruple, as there is a woeful shortage of small cut. The industrial stones had the following prices per carat:—

1939	1940	1941
2.54	2.89	2.54 dollars

The diamond market in 1941 was satisfactory and more so when one took into consideration the many disturbing influences during the war. The demand for gem-stones has been well maintained. Sales of all classes of diamonds exceeded £7 million in 1941.

### *The Diamond Industry in 1946*

For the year ended December 31, 1946, sales by the Diamond Trading Co., Ltd., and Industrial Distributors (1946) Ltd., together reached a total all time record for the industry of £30,000,000. Industrial stones accounted for about 11 per cent of this total. In the first 9 months of the year demand for both types of stone reached an unprecedentedly high level and could not be satisfied by available supplies.

*Production.*—The record sale of diamonds considerably exceeded production and were only possible as the result of accumulated stocks of gem-stones and the release of United Nations' reserve of industrial material. It has been stressed by the selling organization that production for 1947 together with stocks of December 31, 1946, will not be sufficient for sales in 1947 to approach those of 1946.

## VII. USES AND INDUSTRIAL UTILIZATION

Diamond has maintained its place as the most valued gem-stone from very ancient times. The requisites and values of gem-diamond have already been discussed. The hardness possessed by diamond renders it eminently

suitable for use as gem-stones, since the sharpness of its edges, and the corners of the cut stones and the polished facets, are unaffected by long or constant wear.

Till recent years gem-diamonds formed the primary product and off coloured and dark stones occurring side by side the bye-product. It has been found that 50 per cent of the diamonds produced is bort, 25 per cent flawed and off coloured material, but could be cut into jewels and 25 per cent formed colourless material. A good part of the last category is too small and is used for jewellery mountings. Five per cent of the stones is larger than 2 carats, which yield 1 carat cut stones. Thus a great portion of the stones mined is unfit for gem purposes and has found its valuable place in industry.

Sydney H. Ball remarks that American consumption of industrial diamonds has increased five times in the past 25 years from 15 to 40 per cent of the world's sale of rough diamonds. It is also expected that by another decade, the value of industrial diamonds will equal or exceed that of the gem-stones. Industrial diamonds are considered in that country as a strategic mineral required to ensure rapid and efficient armament production. Within a decade the use of industrial diamonds has expanded hundred times, which has produced a reaction in the diamond industry. At first the industrial diamond was a bye-product of which only a small fraction was usually consumed. But now-a-days, it is consumed as fast as it is produced and the U.S.A. alone was expected to use 10 million carats by 1944.

The industrial stones come mostly from Africa; their uses are multifarious. The following are the varieties and their several uses:—

(1) Carbons (Brazilian black diamond) are opaque and appear like pieces of coal; sizes vary from 0.10 to 3,078 carats (the largest known). The large ones are broken and used for the crown of diamond drills. Cleavage is not present, which makes it very tough and of inestimable

value to mining engineers. (2) Ballas is a variety between carbons and is crystalline with no planes of cleavage. It has a radiating structure from a central point; some of them are also spherical. It is very durable and perhaps is the best type of industrial diamonds. It is used for mineral boring and emery wheel truing work. It is rather rare and is obtained from S. Africa and Brazil. (3) Bort consists of imperfectly crystalline diamonds, often a conglomeration of minute crystals, having no clear portions and no cleavage planes. It is useless for gems, but is very hard and its powder is very good for cutting and polishing. Other industrial stones consist of cube formations, grey or brown crystals and melee, weighing less than  $\frac{1}{4}$  carat and is used in glass cutting. The industrial uses mainly consist of truing of abrasive wheels (40 per cent), for core drilling 20 per cent, wire drawing 20 per cent and for other purposes 20 per cent.

War time conditions created a turning point in the great Kimberley industry. The depressing effect of war conditions on world markets has been very much countered by the enormous growth in the demand for industrial diamonds for use in mechanical engineering tools, such as lathe tools, diamond discs, etc. Because of its great hardness, more than 75 per cent of the world's output of diamonds is put to effective use as cutting agents in many classes of machines.

### VIII. PRODUCTION

India was the greatest diamond producing country, but the present output is very small and comparatively unimportant. But recent reports show an annual average production of 1,649 carats. In the quinquennium 1939-1943, the production shows further improvement and the production in 1942 had reached 2,823 carats. Most of the production is from Panna State. The Panna diamonds are brilliant white or bluish white, and are of good quality.

This is very easily sold as India is annually importing diamonds worth a crore of rupees.

*Total value of imports of diamonds and other precious stones in India during 1939-41.*

	1939	1940	1941
Diamonds .. ..	71,38,683	19,09,080	4,62,319
Other precious stones ..	7,15,767	9,52,551	3,82,510
Pearls (real and cultured)	17,92,038	12,73,560	11,56,412
	<u>96,46,488</u>	<u>41,35,191</u>	<u>20,01,241</u>
From U.K. .. ..	8,96,013	3,85,142	3,86,686
„ Netherlands ..	2,57,302	1,01,638	..
„ Belgium ..	64,24,765	15,99,917	250
„ Arabia ..	4,86,144	4,40,634	3,98,489
„ Bahrein islands ..	2,74,841	3,05,058	2,20,541
„ Other countries ..	13,07,423	13,02,802	9,95,275
	<u>96,46,488</u>	<u>41,35,191</u>	<u>20,01,241</u>

Export figures are not included in the accounts relating to the sea-borne trade of India.

World production of gems and industrials in 1941 is estimated at 9,088,000 carats valued at 27 million dollars. Average quality is better than in 1940; but industrial diamonds represent 78 per cent of caratage and gem-stones 22 per cent.

*World production of diamonds during 1937-1941, by countries, in metric carats—including industrial diamonds.*

Country.	1937	1938	1939	1940	1941
Africa—					
Angola ..	626,424	651,265	690,353	784,270	787,000
Bel. Congo. ..	4,925,228	7,205,620	8,344,765	10,900,000	6,106,000
Fr. Equ. Africa ..	5,588	16,013	16,000	16,000	20,000
Fr. West Africa ..	54,687	61,928	56,814	75,000	35,000
Gold Coast Exports ..	1,577,661	1,296,763	1,087,652	825,000	743,000
Sierra Leone ..	913,401	689,621	600,000	750,000	850,000
S.W. Africa ..	196,803	154,856	35,470	30,017	46,614
Tanganyika (exports)	3,234	3,576	3,445	2,250	1,750
Union of S. Africa					
mines and alluvial	1,030,434	1,238,607	1,249,828	523,474	112,300
Brazil .. ..	238,606	235,000	350,000	325,000	325,000
Brit. Guiana ..	35,958	32,522	32,491	26,764	27,000
Other countries ..	6,000	34,200	19,000	31,750	34,350
GRAND TOTAL ..	<u>9,614,024</u>	<u>11,619,971</u>	<u>12,485,318</u>	<u>14,289,525</u>	<u>9,088,014</u>

### *Indian reserves and outlook*

India supplied the world's demand for diamonds from ancient times till the second decade of the eighteenth century, when the Brazilian fields were discovered. Since 1867, South Africa became the most important producer, producing about 95% of the world's diamonds. These Indian diamond fields were exploited mostly by primitive people and by indigenous methods of mining. It is very likely that the Indian fields have not been thoroughly and systematically exploited; there may be areas of diamond gravels still remaining to be exploited. Since modern methods came into vogue, no large enterprise has attempted to work the Indian fields as Brazil and South Africa proved rich and produced large quantities. Now the Brazilian fields are slowly decaying; in South Africa the pipe mines have been closed down, and when the present alluvials became exhausted, it may be that the Indian fields may stand the chance of a re-examination.

It has been observed 'that both practical and scientific opinion is, however, in favour of the explanation that the lessened trade in modern times is more due to the conservative character of the diggers in keeping their art a secret or to the exhaustion of the surface workings which their appliances and means are alone suitable for, than to the complete exhaustion or non-existence of fairly rich unexplored diamond beds. A few centuries ago, diamonds were undoubtedly more extensively produced in India than at the present day. India, was, indeed the first and for a long period known to the European nations.'

Ancient observers have recorded that Indian diamond mines were held for centuries by poor workmen, unaided by science, who had to depend on their hereditary skill. They had also to battle against the adversity and persecution engendered through national disturbances that

shook the Empire particularly from about the period of the Brazilian discovery.

Until a fresh survey of the Indian diamond fields is undertaken, it is difficult to form a correct idea of the present Indian reserves but there is always a scope for mining on a small scale and the production of diamonds occasionally. If all the areas in India are worked seriously the production might be improved. It is difficult to say whether India will ever regain her ancient glory or attain the fame of South Africa or Brazil as a large producer of diamonds.

### SOME FAMOUS INDIAN DIAMONDS

No account of diamonds will be complete without an account of some of the large and famous Indian diamonds, which earned a world wide fame and possessing a special interest. The following are the most important stones:—

1. *Koh-i-noor*.—Some legends are in vogue about its great antiquity even 5,000 years ago. But for the period up till 1304 A.D. no information is available. It is said that in 1304 A.D. Alauddin took it from the king of Malwa. It remained with the Moghuls till 1526, when Ranjit Singh got it from Ahmed Shaw at Lahore. When the Punjab was annexed by the British all the State jewels of Lahore were confiscated by the East India Co. On 3rd June, 1850, it reached Her Majesty, Queen Victoria, the weight being 186 carats. When it was with Aurangzeb, it had a weight of 793 carats. This reduction was due to the unskilfulness of Hortensio Borgio, a Venetian lapidary who had been entrusted with its cutting. This enraged the emperor so much that Borgio was dispossessed of all his property and with great difficulty escaped with his life. The stone had the form of an irregular rosette. It was again recut in 1852. The present weight is  $106\frac{1}{16}$  carats and the stone is of considerable beauty. It is supposed to have been found at Kollur.



2. *The Great Moghul*.—Tavernier states that he saw this stone at the court of Aurangzeb and it weighed at that time  $787\frac{1}{2}$  carats, and also got confounded with Koh-i-noor. Tavernier has recorded two large stones, and hence it is thought that the two are only convertible names. Another theory refers the stone to be cut into three by Borgio: (i) the Koh-i-noor, (ii) the Great Moghul and the third went to some petty chief. When cut it came to 240 carats. The subsequent history of the Great Moghul is a complete blank, and is supposed to have been lost or destroyed. It is presumed to have been found at Kollur about 1650.

3. *Pitt or Regent*.—Though not the largest, it is considered to be the most perfect and beautiful diamond in existence, remarkable alike for its shape, proportion and fine water. Its original weight was 410 carats. It is supposed to have been found at Partial in 1701. The stone came into the hands of William Pitt, Governor of Madras. It was cut to a perfect brilliant, weighing  $163\frac{7}{8}$  carats. Subsequently it was purchased by the Duke of Orleans, Regent of France, for £135,000. It has been treasured as one of the most beautiful and valuable of the jewels belonging to the French nation. This diamond was stolen from the Garde-Meuble in 1792, but came back in a mysterious fashion. The republic then pledged it to a Berlin merchant from whom it was again redeemed. The Emperor Napoleon I used to wear it in the pommel of his sword and always considered it to be the key-stone to all his future greatness. It was shown in the French Exhibition of 1855.

4. *The Orloff or Amsterdam diamond*.—This stone is reported to have formed one of the eyes of a Hindu God, and was stolen away by a French Grenadier of Pondicherry, who passed as an incognito Brahmin. It was first sold to an English sea-captain for Rs.20,000 who in turn sold it to a Jew for Rs.1,20,000. It passed again to another

hand from whom in or about 1772, it was bought by Prince Orloff for presentation to Catherine II for Rs.9 lakhs, and a life annuity of Rs.40,000 and the grant of a Russian nobility to the seller. There is also a legend that it was one of the stones taken away by Nadir Shaw from the Moghuls.

The stone in its outlines resembles Tavernier's Great Moghul, but there is the difference in weight. Another story says that it was brought to Russia and placed in the Russian Imperial sceptre weighing 194½ carats. Like the Koh-i-noor, it has the underside flat, and is rose cut. Water is of any yellowish tinge. Its size is that of a pigeon's egg. It is the largest of diamond in the Russian crown jewels. It is a stone of the finest water, pure and has a brilliant lustre.

5. *The Sancy*.—Its early history is not traceable. It was sold by the King of Portugal to Baron de Sancy, and hence known as the Sancy. It was in his family for more than a century, then with James II of England and afterwards with Louis XIV. It was lost in the French Revolution of 1792 and found again. It was bought by Sir Jamsetjee Jeejeebhoy of Bombay for Rs.2 lakhs. It is almond shaped, of very fine water, and weighs 53½ carats. The cut is evidently Indian and the stone is covered all over with tiny facets.

6. *The Nizam*.—This stone was found at Golconda and weighed 340 carats (afterwards 277 carats). It was broken in the year of the Indian Mutiny. It is now presumed to be in the possession of the Nizam.

7. *The Florentine Brilliant*.—The Grand Duke of Tuscany. The Austrian Yellow was valued at Rs.10½ lakhs. It was double rose cut and weighed 139½ carats. Charles the Bold had three diamonds of great beauty and value. The history of the two is confused with one another, and the third is the Sancy already referred to. After passing

through a number of hands, it finally passed into the hands of Pope Julius II, who presented it to the Emperor of Austria.

8. *The Pigott diamond*.—This stone was taken away from India by Lord Pigott about 1775 and passed through several hands. It is brilliant cut and weighed  $82\frac{1}{4}$  carats. It was once sold for Rs.  $3\frac{1}{4}$  lakhs.

9. *The Hope diamond*.—This beautiful diamond was believed to have been taken from India. It has a steely or greenish blue colour, an extremely rare tint in diamonds, a brilliant lustre and a fine play of colours. It has been known since 1830, and its original weight was  $112\frac{3}{16}$  carats, but the present weight is only  $44\frac{1}{4}$  carats. It was found at the Kollur mines, stolen from an Indian temple by Tavernier in 1642 and sold by him to Louis XIV in 1668. It finally came into the hands of Thomas Phillip Hope. The stone is supposed to have brought ill-luck in its train. It figured a great deal in the Great Exhibition of 1851.

10. *The Great table of Tavernier*.—It was seen by him in 1642. According to him it weighed  $242\frac{3}{16}$  carats and that it was the largest diamond he had seen in India in the hands of dealers. His offer of Rs. 4 lakhs for this stone was rejected.

11. *Dariya-i-noor*.—‘River of Light’—It was rose cut and weighed 186 carats. It appears to have been captured by Nadir Shaw at Delhi and now is the largest diamond in the Persian collection.

Besides the above there are other large diamonds obtained from other countries as the Mattom diamond from Mattom in Borneo weighing 367 carats, (2) the Braganza from Brazil, that weighed 1,680 carats, (3) the Star of the South, found in Brazil and weighed  $254\frac{1}{2}$  carats, which was cut to a brilliant of 125 carats, a diamond of the purest water, exhibiting a lovely rose tint under light.

### *Other large diamonds*

1. The Portuguese crown has many large and brilliant diamonds.
2. The Brazilian Government is in possession of some large and curious stones.
3. The Spanish Government was also very rich in diamonds and other jewels.
4. The Russian treasury had a brilliant ruby coloured diamond of 10 carats.
5. The Turkish Government is said to have two large diamonds of 84 and 147 carats in weight.

Many large diamonds of brilliancy and weight are in Burma and China, and with the Indian Princes and Nobility and also in the families of the Burdwan Maharaj, Nawab of Dacca, etc., and also some rich families in Calcutta, e.g. *Tagore Brilliant*, *Sukh-tara*, etc.

6. The *Cullinan* was found in the Premier mine, near Pretoria, Transvaal, on 25th January, 1905. It measured  $4 \times 2\frac{1}{2} \times 2$  inches and weighed 621.20 grams = 3,106 carats = 1.3695 lb. avoirdupois, named after the Chairman of the Premier Co., Sir Thomas Cullinan. It was presented to King Edward VII. This perfectly clear and colourless stone was cleaved and cut in Amsterdam into 9 larger and 96 small brilliants. These are with the crown jewels—other large stones from the Premier mine were of 1,683½ carats in 1912 and 1,500 carats in 1924.

7. *Excelsior* was found in 1893 in Jagersfontein mine in Orange Free State. It weighed 995.2 carats.

8. *Jonker* was obtained from Elandsfontein alluvial workings, near the Premier mine. It was sold to the Diamond Corporation for £75,000 and passed to an American dealer for almost double this amount.

9. *Jubilee*, another large stone from the Jagersfontein mine in Orange Free State, was found in 1895, and was cut in 1897. It was a flattened and rounded octahedron,

weighing 650.8 carats. It was cut into a brilliant of 245.35 carats and a smaller pendiloque brilliant of 13.35 carats.

10. The *Imperial*, also known as the *Victoria* or 'Great White' came probably from the Jagersfontein mine. It weighed 469 carats and yielded two brilliants of 184.5 and 20.5 carats.

11. The De Beers diamond, found in 1888 in the De Beer's mine at Kimberley was more regular in shape being an octahedron with curved faces. It was a pale-yellow stone weighing 440 carats, and yielded a brilliant of 234.5 carats; the yield was  $53\frac{1}{2}\%$ .

12. The *Stewart* was a river stone from South Africa found in 1872 in the Vaal. It weighed 296 carats and yielded a brilliant of 123 carats. Many other larger stones have been obtained from South Africa but were not of gem quality, being off coloured and sold as bort.

*Brazil.* The 'Star of the South' was found at Bagagem in Minas Geraes in 1853. It weighed 261.88 carats and was cut as a brilliant of 128.5 carats. Both this and the smaller 'Dresden' were acquired by the Gaekwar of Baroda. The 'Star of Mine', weighing 179.37 carats, was found at Bagagem in 1911.

The Vargas diamond was found in Coromandel, Brazil, and named after the President of that country. It weighed 726.6 carats. The stone was brought to the U.S. for cutting, which was begun early in 1941, with the expectation of producing 23 gems varying from 5-50 carats from half of the stone, the other half being reduced to chips and dust in the course of the cutting and polishing.

*Coloured diamonds.*—Large sized coloured stones are rare. The Hope blue diamond weighed  $45\frac{1}{2}$  carats and is of a dull slaty blue colour and perfectly transparent. It was sold in Paris in 1909 and is now in America. The 'Dresden Green', a clear apple green brilliant of 41 carats was of Indian origin. The 'Tiffany Yellow' is a canary

yellow brilliant of  $128\frac{1}{2}$  carats and belongs to Tiffany & Co. of New York. It was found in the Kimberley mine at Kimberley, South Africa.

## CHAPTER XII

### THE CORUNDUM FAMILY—RUBY AND SAPPHIRE

#### INTRODUCTION

Ruby, sapphire and emery were known to the ancients, but their true relationship came to be realized only recently. Formerly the spinels were also classed with the rubies, but are now separated. Charles Francis Greville in 1798 introduced the now well-known name 'Corundum' for this mineral species. Count de Bournon was also responsible for classifying corundum (1802), but the eastern nations had known it for several centuries. The origin of most corundum, ruby and sapphire in ancient times was from the east. The name is also of Indian origin, 'korund' in Hindi and 'kuruvinda' in Sanskrit. The ruby is known as 'oriental ruby' or 'Padmaraga' (= red lotus) which was the best favourite and most valuable of all gem-stones. The ancient writers described it as having the power of shining in the absence of all light, the fact being the ruby becomes phosphorescent by being exposed to the sun. Ruby is spoken of in the book of Job, in the Proverbs and the Bible. The breast plate of the high priest is said to have had rubies set in it.

#### PHYSICAL CHARACTERS

Ruby is the gem variety of corundum, which crystallizes in the rhombohedral form. Corundum and ruby crystallize in flat forms with the basal pinacoid and rhombohedron, and the sapphire in double pyramids with the basal pinacoid. The angle between the normals to the basal pinacoid and rhombohedron is  $57^{\circ} 34'$  which is a fundamental

constant for corundum. The ruby has a flatter habit, whilst the sapphire has a taller habit, and a combination of these gives rise to barrel shaped crystals. The faces are striated and grooved parallel to the horizontal edges. There is also lamellar twinning and crystals may break easily along this direction. It is not to be mistaken for cleavage for it is only parting. This lamellar twinning is perhaps due to earth pressures. It is also considered the cause of 'silk' in ruby and of asterism in star stones. Contact twins are rare.

Gem corundum forms small crystals while corundum may form larger crystals. The largest corundum crystal known measures 2 ft. 3 in. in height and weighs 335 lb. Another large crystal in the British Museum weighs 341 lb. The habit of ruby and corundum crystals is related possibly to the nature and composition of the impurities in the mineral. In hardness corundum comes next to diamond, but it is exceeded by carborundum and by some artificially made carbides. The specific gravity of corundum slightly varies from 4 (3.90–4.10). This variation may be due to the presence of cavities and impurities. Gem varieties are transparent, but common corundum is transparent to translucent, or opaque and varies in colour. The optical characters are those typical of a uniaxial crystal of negative sign. So basal sections are isotropic and resemble spinel, but in convergent polarized light the uniaxial interference figure will at once mark the two minerals. Other directions will show birefringence and dichroism. Refractive index  $\omega = 1.768$ ,  $\epsilon = 1.760$ : dispersion 0.018—which is much less than in diamond; hence they do not flash prismatic colours and are less brilliant and depend on their colour for their appeal. When viewed in the direction of  $c$  axis a deeper colour is seen, than when viewed through prism faces. So in cutting the table facet, it is done parallel to the basal plane ( $c$ ) of the crystal. Pleochroic colours in ruby are as follows:—Ordinary ray colour = deep red with

a violet tinge, extraordinary ray colour = light yellowish red. Sapphire shows blue for ordinary ray and yellowish blue for extraordinary ray.

The colour of corundum has a wide range. Red corundum is known as ruby, and formerly was confused with spinel and garnet. The colour may vary from deep red to pale pink. The colour of the best ruby is known as 'pigeon's blood red', which has been widely copied from book to book. For sapphire, the finest colour is a royal blue, a dark sky blue or Indra Neelā in Sanskrit of remarkable purity and evenness of distribution. The next best colour is the corn-flower blue of Kashmir sapphires. But the colour may vary from inky blue to sky blue, a pale greyish blue, velvety blue, and corn-flower blue, which are very much appreciated. The terms ruby and sapphire connote definite meanings, but corundum of other colours has been much confused in names. Yellow sapphire is known as 'oriental topaz'.

When exposed to ultra-violet rays, crystals or cut stones of ruby are seen to glow with a brilliant red light as if on fire. Hence it was known as carbuncle. This phenomenon is known as fluorescence. Yellow corundum and some sapphires give a yellow glow.

'Silk' and 'asterism' are seen in native corundum but not in synthetic gem corundum. In 'asterism' a six rayed or twelve rayed star may be seen, when examined in light and when the stone is cut en cabochon, or a dome shaped form, the base of which coincides with the basal plane of the crystal. Star rubies and star sapphires are also valuable gem-stones.

### USES

The precious forms of corundum, *i.e.* ruby and sapphire are valuable and costly gem-stones. The impure forms and emery are used in industry as abrasive. Due to its hardness it is used as an abrasive agent for grinding and



polishing. It is applied in a powdered form to paper (emery paper) and is used in the form of wheels or hones. The powder is used in different grades of fineness by lapidaries for grinding gem-stones. Another important application of corundum due to its hardness is for pivot supports in delicate instruments as jewel bearings of watches and also for bearings in scientific instruments.

### GRADES

(a) Rubies and sapphires are the gem varieties of corundum. Ruby has various shades of red, the best colour being the pigeon's blood red, a shade of red slightly inclined to purple. (b) All precious corundum other than red is generally called sapphire and the true sapphire is a royal blue to a corn-flower blue, also known as Kashmir blue. Sapphires of other colours have separate names. (c) Star rubies and star sapphires, (d) Common corundum and emery are not useful for gem purposes. Corundum usually consists of opaque crystals or masses with dull colours. Emery is a black granular mixture of corundum with magnetite, hematite, quartz and spinel. Both are used for abrasive purposes.

Rubies were known in India from very ancient times and came chiefly from Ceylon and Burma. The different varieties were named according to the colour. The ordinary good ruby is known as 'Padmaraga'. Spinel was also included under corundum. The following are the varieties:—

- |   |           |
|---|-----------|
| (a) Padmaraga—oriental ruby = Vipra or Brahmin. |           |
| (b) Kuruvinda—rubicelle = Kshatriya.            |           |
| (c) Saughandika—spinel = Vaisya                 | } Spinel. |
| (d) Mansa-khanda—balas ruby = Sudra             |           |

The rubies are also said to have bad properties as in the case of diamonds as shown below:—

<i>Name.</i>	<i>Property.</i>	<i>Evil effect.</i>
1. Dwichhaya	Emits a two-fold shade.	Death of friends and loss.
2. Virupa ..	Bears a mark like a bird's foot.	Brings humiliation to owner.
3. Samveda	Mark like a rift.	Owner liable to a blow from a weapon.
4. Asovana	As if immersed in milk.	Numerous evils.
5. Kokila ..	Mark like a drop of honey.	Inimical to life, wealth and fame.
6. Jara ..	Discoloured.	Loss of wealth.
7. Dhumra ..	Looks like smoke.	Liable to lightning stroke.

According to the Hindu lore, bad rubies should never be worn although set along with best rubies. The rough test for a padmaraga was to rub it on a whetstone or tested padmaraga—the false one will receive scratches. Except diamond and kuruvinda no gem can scratch upon padmaraga or indranila. All gems derive their value from lustre and colour and those lacking in colour and lustre are of little worth. The Hindus also considered that the treasuring of padmaraga furnished with every perfection is as meritorious as the celebration of *Aswamedhayajna* and leads to wealth, success and long life.

### RUBY CUTTING

It is done by means of diamond powder on an iron-wheel or skeif, and polished on a copper plate with tripolis and water. In the East, corundum powder for polishing is used. The usual form of cutting is a mixed half brilliant. Silky and imperfect ones are cabochon cut so also star stones. The centre of the star should be in the middle of the stone. Engraving on rubies are said to be still in existence as old as 500 B.C. The Greeks and Italians specialized in this art.

## THE PRICE OF RUBY

As the Burmese kings did not allow rubies to go out of Burma, they were more valuable than diamonds. In 1880, rubies under  $\frac{1}{2}$  a carat if English cut, cost from £4-£10, and if Indian cut cost from £1-£4. Stones of greater weight than 4 carats, being rarities fetched fancy prices. Rubies with flaws and specks or only having silky or milky appearance or pale in colour have low prices. A pale ruby of 4 carats might be worth less than £12; spinels, balas rubies and garnets have been passed off as rubies. Rubies of a fine colour and which are clear and flawless are very valuable and cost as much as Rs.4,000 per carat. Sapphires are less expensive and may cost from Rs.20 to Rs. 400 per carat.

## MARVELLOUS AND MEDICINAL POWERS ATTRIBUTED TO RUBY

Superstitions even amounting to stupidity played a great part in the attribution of the marvellous properties of precious stones. The ancients used a powder of rubies, topaz, emerald, sapphire and hyacinth as a medicine of great value. The physicians used to pocket the real gem by substituting false ones in their places. The ruby used internally or externally was an antidote to poison and plague. It drove away sadness, evil thoughts and wicked spirits. It was used as an amulet against all illness. It would warn the wearer of the approach of any misfortune, by a change of colour to blackness and would recover its brightness after the peril passed away.

## OCCURRENCE

Corundum is composed of aluminium and oxygen, and when they combine with silicon form alumino-silicates, which make up half of the earth's crust. So corundum cannot occur in a rock that contains an excess of silica, but can in a rock with an excess of alumina over silica.

It is found in syenites, peridotites, serpentine as well as in some crystalline schists and crystalline limestone. So it does not occur everywhere. The rocks concerned are igneous and metamorphic which also point to their origin.

The minerals associated with corundum are spinel, tourmaline, kyanite, magnetite, chlorite and nephelite. The gem varieties of corundum are obtained very rarely and only in a few places. The countries which produce most of the world's gem corundum are Burma, Siam, Ceylon and India (Kashmir). Gem corundum has also been obtained in Afghanistan, China, the Ural mountains and Queensland. In the U.S.A. fine rubies have been found in the crystalline rocks of N. Carolina, and sapphires and rubies along the Upper Missouri River, near Helena, Montana. Some dark blue and greenish blue corundum have also been reported from Australia. Africa has not produced any gem corundum so far. In the U.S.A. corundum has been mined to a small extent at a few places, a little gem corundum being found occasionally.

(i) *Afghanistan*.—Rubies were obtained from Afghanistan near Jagdallak with sapphires, large quantities of garnets, spinels, etc., in a belt of highly crystalline limestone.

(ii) *Upper Burma*.—The ruby mines of Upper Burma form the principal source of the world's supply of gem corundum which is found in a highly crystalline limestone.

(iii) *Mandalay-Sagyin hills*.—This area was worked at one time for sapphires, spinels, rubies, etc. Now there is not much activity in this area.

(iv) *Myitkyina-Nanyazeik*.—This area also produced rubies, sapphires and spinels from the detritus afforded by the disintegration of crystalline limestone surrounded by intrusive masses of granite. Neither ruby nor spinel appear to be abundant in this area.

(v) *Ceylon*.—Ceylon is also renowned for its gem-stones and the gravels containing gems are known as the 'Illam' which underlies the soil in paddy-fields.

The tract of the Burma ruby mines forms the most important area for rubies and spinel in the world, and they have been found in the extensive bands or lenticles of crystalline limestone or marble. These mines were known to the Europeans from the fifteenth century. Due to the denudation of enormous quantities of rock, the gem-stones have been concentrated in pockets in the debris in mud filled cavities, and caverns such as are well known in the limestone districts. The principal workings have so far been in alluvial deposits in the valley bottoms. The gem bearing gravel is known in Mogok as *byon*. The *byon* or ruby strata is either alluvial or a rotten rock between the limestones and the tongues of granite intrusions which form little zones of pneumatolysis. The granite-limestone contact is always held favourable for the *byon*. The associated minerals in the *byon* are ruby, sapphire, spinel, chrysoberyl, tourmaline, garnet, zircon, beryl, quartz, scapolite, apatite and danburite.

The ruby mines are also famous for sapphires which are found like the ruby in the alluvial deposits. The Mogok valley has produced a few magnificent sapphires, though specially reputed for its rubies. It is not found in the limestone as the ruby but is found in felspathic and weathered igneous rocks and corundum syenites.

#### GEM MINING

*Mogok area.*—Sapphire is found in the ruby mines from near Kathe, at Kyaungdwin near Kathe, from Ingaung near Gwebin and Kabaing. The majority of the finest sapphires were obtained from this area. Bernardmyo and Chaunggyi also produced some good sapphires. Sapphires also occur in hill-side or valley deposits. Sapphires attain much larger sizes than the rubies. Stones of 293 and 630 carats weight were found at Kathe in 1930 and 1932. Mogok produced a stone of 514 carats, and at Gwebin a stone of 1,000 carats in 1929. They are

much cheaper than rubies, and the finest quality stones of medium size cost about 1/10 of the value of similar rubies. In 1929, the sapphire produced near Gwebin weighing 1,000 carats was purchased by Mr. A. Ramsay for £13,000. He cut it into 9 magnificent sapphires weighing from 66.50 to 4.33 metric carats. Star sapphires of excellent quality and colour are also obtained.

*Ceylon.*—Ceylon is also renowned for its sapphires, and is one of the great gem producing countries of the world. Ratnapura means a city of gems. The sapphire occurs in a gravel known as the *Illam* resting on the surface of the decomposing country rock. Besides sapphire the *Illam* also contains other semi-precious stones as amethyst, aquamarine, chrysoberyl, garnet, moonstone, peridot, ruby, spinel, topaz, tourmaline and zircon. The sapphires originate in quartz from pegmatites cutting the gneissic series. The gems are found in all deposits along the course of the present rivers or of those of ancient times. The chief gem-mining districts are those about Balanguda, Rakawana and Ratnapura. The annual output of gems in Ceylon is reported to be worth 8 or 9 lakhs of rupees. Occasional discovery of large stones cause this value to rise. The most valuable of the gems produced in Ceylon are deep blue sapphires weighing from 200 to 7,200 carats. Fine specimens up to 100 carats in weight are not uncommon. The world's largest sapphire, 42 lb. in weight, came from Ceylon, and was sent to England for cutting.

*Kashmir.*—Sapphires are known from Kashmir since 1881. They occur at Soomjam (Sumsam), Padar district. The mines lie  $2\frac{1}{2}$  miles W.  $30^{\circ}$  N. of Soomjam (the highest village, consisting of a few houses on the south side of the lofty hill ranges), dividing Zaskar from the Chenab drainage area. The mines lie at a height of 14,800 to 14,950 ft. and the outcrops lie hidden away in the higher and remoter parts of the mountains. They are associated

with granite or other igneous intrusions, piercing the older and more metamorphosed crystalline schists or richly concentrated in pegmatite off-shoots.

Along with the sapphire, some pale rubies and semi-precious gems as aquamarine, rubicelle, green tourmaline quartz, felspar and serpentine occur. Of the latter the most important is the aquamarine of Daso.

The Soomjam area was discovered in 1881-1882, and also visited by Mallet in 1882. The mines produced well during the period 1882-1887, followed by a lull and since 1926 fresh attempts were made. Large quantities of corundum sapphire have been obtained from a central part of the New Mines area. The corundum is patchily coloured, varying from pale to azure and deep blue. The matrix is a small patch of white kaolin or china clay which is tough, and passes down to a pegmatite containing felspar, and the sapphire is embedded in it. The pegmatite also contains tourmaline, garnet, beryl (aquamarine) and corundum. The pegmatite is considered to form numerous lenticles arranged in series or rows. In the New Mines, these lenticles of pegmatite have a base of actinolite and tremolite, which are again in turn found to be distributed in crystalline limestone.

In the New Mines, the sapphires are distributed as thick as plums in a pudding, in small lenticles of the kaolinized pegmatite which are either enclosed or are intrusives in the tremolite-actinolite rock, the latter being probably the local modifications of the crystalline limestone. The corundum sapphire rocks are supposed to have a more extended distribution than hitherto known. Some placer deposits are also supposed to exist.

The stones vary in colour from light to deep sky blue. The greater number of the stones are of a deep and lively blue, which shows up well in artificial light. The Kashmir stones are also very popular and command very high prices.

In Siam, ruby and sapphire occur together in the province of Chantabun and Krat in the south-east, and was known only in alluvial deposits. The Siam sapphires are also of good colour and quality.

A large stock of sapphires is believed to be kept in the Kashmir treasury on account of its location. The mining of sapphires could not be carried throughout the year.

Gem mining is never attempted on solid rocks, since gem minerals are only sparingly and sporadically distributed. Nature has broken down large masses of rock, leaving the gem-stones in the more easily worked debris.

The ruby mines of Burma are known to be working since the fifteenth century, under the close supervision of the Burmese kings. On the annexation of Burma by the British, the Burma Ruby Mines Co. was floated in London in 1885. This firm worked for forty years and went into liquidation in 1925, and had produced £2½ millions worth of gem-stones. One of the famous rubies, obtained from this area is the 'Peace Ruby' found on the Armistice day in 1918, whose weight when cut was 23 carats. It was sold for Rs.3 lakhs. The Burma Ruby Mines Co. mostly worked at a loss and on its liquidation, ruby mining on modern methods also came to an end. One of the reasons for this was the flooding of the market with synthetic rubies.

The operations of this concern were confined to removing and washing gravels from valleys in the neighbourhood of Mogok, Kyatpyin, Kathe and Luda valleys. These are the centres where mining activity is still present. Mining on extraordinary licence was carried to a small extent with modern machinery. The indigenous mining methods are still pursued and are ever likely to continue, since mining on a large scale with machinery has proved unremunerative. There are three methods of mining in vogue depending on the season and the nature of the country.

(i) *Twinlons or Twin-Mining in the dry season*.—It consists of small round pits, the diameter of which will



just allow a man to get down by placing his feet in niches on the sides. The pits are not numbered, and go down to a depth of twenty to forty feet. If one 'twin' happens to produce a stone all the miners rush to the same spot, and dig in close proximity. Twins may go down as deep as ninety feet. On reaching the *byon*, further excavation follows in the direction of the *byon* to about thirty to forty feet in radius. Generally three men work each mine, two do the digging and the third does the hauling of the dug-up material which is done by long bamboo levers. The earth, dug up until the *byon* is reached, is thrown away. The *byon* is a yellow brownish, gravelly clay, at times firm, at times sandy, and often full of gravel. The *byon* is gathered and safely stored for washing.

(ii) *Hmyawdwins* or *Hmyaws*.—These are very popular and practised on hill-sides and in steep valleys, and work usually throughout the year. Some have worked for long periods ranging from 50 to 60 years. The cuttings made on the hill-sides vary much in size. The water-supply is of great importance, and is obtained from long and perennial sources by channels dug round the hills. *Hmyaw* mining requires a long period of undisturbed ownership for tranquil mining, for which local unwritten laws have sprung up by custom, so that usually no interference is caused by the neighbouring miners.

The *byon* is usually found twenty to twenty-five feet below the surface. The water brought from channels, is sprayed by passing it along bamboos suitably cut. This loosens the top soil, which is removed and the *byon* is exposed. The *byon* is washed in a flat circular floor constructed near it. Water is diverted into it along with the *byon* in the form of sprays and the washed up material enters the tailing channel, which is often covered. The heavy material is usually trapped here, and it is periodically removed and examined. The precious stones

are sorted and the refuse thrown away. The concentrate is then sorted for different precious stones.

(iii) *Loodwins* or *Loos*.—These are cavernous holes in the limestone and may run tortuously for long distances even 100–200 ft. in depth. There are pockets of *byon* in the crevices and at times even very rich pockets, but all the *byon* has to be carried up which is a laborious process. It is a dangerous form of working and is now becoming unpopular.

*Ye-ban-gwet*.—When the *byon* is collected, it is taken to a convenient place where water is available. A shallow basin is constructed with stones. *Ye-ban-gwet* is cemented with clay and is slightly sloping towards the tailing channel. The *byon* is placed in the basin and water sprayed on it as in a *Hmyawdwin*. The *byon* is well crushed by trampling over it or with mammootties. A small obstruction lower than the sides of the *Ye-ban-gwet* is placed across the channel. The clay and light sands pass over it in the surplus water, and the heavier concentrates are held back. Pits are kept in the channel also. Both rubies and sapphires are obtained from the same mines. In Ceylon the mining is done more for sapphire than for other stones, as it is the most important gem-stone produced. It is produced by alluvial washing, or deep mining by sinking wells into the gem gravel or *Illam*. The best stones from all these areas find their way to Europe and America.

#### MARKETING

In Burma the licensee or his wife is always nearby when the working is in progress. The licensee grades the day's find and if it happens to be good, a number of brokers are always ready to examine them and advise them. The stones are sorted according to size, quality and quantity and then counted and weighed. They are then taken to the stone bazaar at Kyatpyin or Mogok, or disposed

of through brokers. The Burma Ruby Mines Co. used to hold periodical auctions of their stocks at Mogok. In the case of large stones, the stones are kept in the owner's house, and on a customer examining them, he makes an offer or asks the owner to keep them sealed till he makes a decision. They are kept under seal until the first customer gives his decision and if he does not buy them, other customers are allowed to see them.

The purchase of gem-stones is a tortuous business, in which a secret code of fixing prices is employed. After examining the stone with the aid of the broker and after due consultation, the hands of the parties pass under their sleeves or under a towel or a cloth, and then two mute faces look at each other. Not a word is spoken. The buyer holds a particular finger in a particular part and according to the quality and weight of the stone, the parties understand whether the amount is of 2, 3, 4 or 5 digits. The hands are then withdrawn and the offer is noted in their books. It is known as the language of the fingers.

When a deal is concluded, the stones are placed in a rag or envelope and sealed by the buyer, and the stone is kept with the seller until the amount is paid. Brokerage is paid by both the parties.

The market for rubies and sapphires is worldwide. Representatives from Europe and America were often found in Mogok, in addition to the Indian merchants, who were permanently stationed there. Some of the Indian merchants have also their representatives in Paris and New York. The large stones find a quick sale, and are sent to Europe or America, and the smaller stones are bought for the Indian market. With the Japanese invasion of Burma, the area passed into Japanese hands which must have caused considerable disturbance. But with the re-conquest of Burma and resettlement, conditions may again be brought to normal soon. In the pre-war days, Paris

usually supplied the West with the coloured stones, but since the beginning of the war Bombay has taken its place and a cutting industry is thriving at Cambay.

Rubies of good colour, water and weight are seldom found and they are much more costly than diamond or sapphire. Rubies above 10 carats in weight are considered exceptional gems. Sapphires are also sold with the rubies and the same methods prevail in its mining industry and marketing. Sapphires of good quality as the rubies always find their way to Europe and America. The smaller and cheaper stones are sold by vendors at Mogok, who find good customers in tourists, as well as local purchasers and in India. The rubies are considered more important.

The Ruby Mines area must contain vast quantities of the ruby gravel, which will support the indigenous mining for ever and the miners always hope to get big stones. The speculative spirit is never lacking even amongst poor people. A number of persons join and run a mine even when one cannot do it alone.

#### CELEBRATED RUBIES

Tavernier has stated that the King of Visapore had a very fine ruby weighing 50 carats. The King of Burma had an extraordinary ruby of a pigeon's egg size. The Crown jewels of France had a large ruby, cut into the form of a dragon with extended wings. Russia had a ruby of a pigeon's egg size in the crown of Empress Catherine. The Austrian Crown jewels had several rubies of good size and quality. Two stones were sent to England in 1875, one weighing 37 carats and the other  $47\frac{1}{8}$  carats. The former fetched a lakh of rupees. Some of the larger stones, considered as rubies, have been proved to be spinels. Some good rubies are also said to be in India in the possession of some of the large Hindu families. The 'Peace Ruby' has already been referred to. Thousands of crudely cut rubies set in Burmese Regalia were removed to England

from the palace of King Thibaw at Mandalay. They are now exhibited in the Indian Museum in London.

Synthetic rubies and sapphires are also sold in large quantities for gem and industrial purposes, because they are relatively inexpensive and show more uniform characters, and are given a range of very attractive colors. The stones are identical in their characters. They are considered inferior, because they could be produced cheap and have caused severe competition in the trade.

## CHAPTER XIII

### THE SPINEL GROUP

#### INTRODUCTION

SPINEL was also known from ancient times along with the ruby and was classed with the ruby by mistake. It was known as spinel ruby or ruby spinel, which has a fine lively red with a cinnamon tint about it, but is inferior to the true ruby in brilliance. Spinel and ruby are always associated with the gem gravels. The gem rubies, sapphire and spinel could easily be identified as spinel is softer, lighter, isotropic and non-pleochroic. The Indian names were *Saugandhika*, classed as Vaisya ruby, and *Mansa-khanda*—Balas ruby as Sudra ruby, and these were included in the rubies, though by chemical composition and crystallization they are entirely separate.

#### PHYSICAL PROPERTIES

It crystallizes in the cubic system, octahedron being the common form. Twinning is also frequent, two octahedra having grown back to back in symmetrical position. It is known as spinel twin and other minerals also show similar twinning. Cleavage is imperfect and octahedral; fracture

conchoidal. Hardness = 8. Specific gravity = 3·5 to 4·1, and for gem varieties it is 3·5 to 3·7.

The gem quality spinels have a wide range of colours such as crimson, pink, yellow, brown, green, blue, purple, violet and black. The red and green varieties are thought to have been coloured by chromium, and the blue variety by cobalt. Lustre: Vitreous; splendid to dull and the mineral varies from transparent to opaque. Refractive index = 1·72. Dispersion = 0·020. Isotropic.

The general chemical formula may be written as  $RO.R_2O_3$  or  $MR_2O_4$ ; M stands for aluminium, ferric iron, manganese or chromium. Such a combination yields quite a wide range of minerals. Spinel proper is  $MgO.Al_2O_3$ . The magnesia may in part be replaced by ferrous iron, zinc, manganese or cobalt, and the ferric iron by chromium.

### USES

The spinels form such transparent and sparkling crystals, that, when they have the ruby colour, they may be even sold as a ruby. Good gem spinel also fetches a decent price. Good crystals of spinel without colour are not much in demand.

### GRADES OF VARIETIES

1. *Ruby spinel or spinel ruby*.—It is deep red and transparent, the most popular gem variety, also known in India as *Lal rumani* or the 'Pomegranate ruby'.

2. *Balas ruby*.—Rose red to pink, has the same composition as the spinel. The Greeks connected 'Balas' with 'Palatius' as they supposed it to be the matrix in which the ruby was found.

3. *Rubicelle*.—Yellow to orange red.

4. *Almandine*.—Violet and purple.

5. *Sapphirine*.—Blue spinel.

6. *Chlorospinel*.—Iron bearing and of a grass-green colour.

## OCCURRENCE

In nature spinel is a constant companion of corundum. It occurs in the same rocks under the same conditions but has some magnesia in addition. Good spinels have been obtained from Ceylon, Siam and Burma. It is also found in Mysore, Madagascar, Australia, Afghanistan and Brazil. The spinel occurs in the crystalline limestone with corundum or ruby in the Mogok stone tract, and has been found under the same conditions as the ruby. In the presence of magnesia, the  $\text{Al}_2\text{O}_3$  forms spinel instead of corundum. It is also found in serpentine, gneiss and in gravels in Ceylon, Burma and Siam. Spinel has also been reported from the old ruby mines of Afghanistan and the sands of the Irrawaddy above Myitkyina. Spinel occurs in good crystals more often than the ruby, but larger crystals are rare. Crystals of good ruby colour only fetch about half the price of the ruby. In Ceylon Balas ruby, blue spinel and green spinel are found. In gem sands, three-fourths of the material is spinel. The spinel may also be opaque, dull and semi-transparent. Other varieties of spinel occur in the following places: blue spinel—Baluchistan; chloro-spinels—Aker, Sweden, Antwerp and Ceylon; black spinel (Ceylonite)—Ceylon, Bohemia, Tyrol, Russia, etc.; Automolite (zinc spinel)—Sweden; Balas from Ballahia on the Upper Oxus described by Marco Polo.

## INDUSTRY

The spinel is usually obtained along with the ruby and sapphire, and is sold along with cheap rubies and sapphires by vendors at Mogok. Nowadays synthetic spinels of gem quality are made with a wide range of colours in large amounts by the Verneuil process.

The spinel is cut on an iron wheel with emery or diamond powder and polished on a copper one. The form is usually

the mixed cut. Spinel is also mistaken for garnet or jacinth due to colour, but it has a lower hardness.

### REPUTED SPINELS

Most of the spinels were first taken to be rubies and were latterly recognized as spinels: (1) Rudolph II's ruby. It was 100 carats in weight and is now said to be a spinel. (2) The ruby set in the crown of His Imperial Majesty is now considered to be a spinel. In the exhibition of 1862, two large spinels were shown. They weighed 197 and  $102\frac{1}{4}$  carats before cutting and 81 and  $72\frac{1}{2}$  carats respectively after cutting. The French crown jewels also contained a number of spinel rubies, as for instance  $56\frac{3}{4}$  carats and blue spinel  $37\frac{3}{8}$  carats.

## CHAPTER XIV

### CHRYSOBERYL

#### INTRODUCTION AND PHYSICAL PROPERTIES

CHRYSOBERYL means yellow beryl and it is an ancient name. Its variety, cat's eye, was well-known and appreciated from ancient times. It was known as 'Vaidooryam' in India. This mineral was recognized before the discovery of the element beryllium, which is an essential constituent of the mineral. It crystallizes in the orthorhombic system and forms heart-shaped and pseudo-hexagonal twins. These crystals are grown together with interpenetration. The mineral has a pinacoidal cleavage and conchoidal fracture. Hardness =  $8\frac{1}{2}$ . Specific gravity = 3.5 to 3.8. Colour varies from pale yellow, brown or green. Lustre: Vitreous and silky in cat's eye. Transparent to translucent. Mean refractive index = 1.75. Double refraction = 0.010 and dispersion = 0.015. Optically positive. Composition:  $\text{BeO} \cdot \text{Al}_2\text{O}_3$ . It ranks equally as a precious stone with spinel and there are no other uses.



## GRADES

There are three varieties of chrysoberyl: (1) The yellow-green variety is known as 'chrysolite' which is a name also applied to olivine. There is also a chance of mistaking chrysoberyl without chatoyancy for olivine or chrysolite, whose hardness is much lower than that of chrysoberyl. (2) Cat's eye is the chatoyant, opalescent variety which is also known as cymophane with a silky lustre and green colour. This stone when cut en cabochon has an attractive band of light on the stone, which changes on rotation. The play of light in a certain direction amounts to a phosphorescent brilliance and is found in various colours. This chatoyancy is only an accidental character. This is a popular stone and the best quality stones fetch good prices.

This has been called by the Hindus as 'Vaidooryam', and has also been classed into 4 castes as in the case of other precious stones: (1) Brahmin—white cat's eye with a gleam of blue, (2) Kshatriya—white cat's eye with a gleam of red, (3) Vaisya—yellow cat's eye with a blue lustre, (4) Sudra—purely blue cat's eye. The cat's eye which sparkles beautifully is also known as 'sutra'. It has also good qualities and the usual defects. The popular colours are apple green and dark olive. When held against the light, the stone resembles the contracted pupil of a cat. It has double refraction and acquires electricity by friction.

Alexandrite is another interesting variety, with a dark green colour by daylight and deep red by artificial light. It is also strangely pleochroic—chromium is supposed to be the cause of colour in Alexandrite.

## MODE OF CUTTING

The mode of cutting adopted is en cabochon. It is cut on a copper wheel with emery and polished with Tripoli.

## OCCURRENCE

Chrysoberyl occurs in gneiss, mica-schist and granite and with stream deposits with such minerals as beryl, tourmaline and apatite: (i) The variety 'chrysolite' is found in Brazil, Haddam (Connecticut), Greensfield, N. York, and Norway. (ii) Cat's eye variety is obtained from Ceylon, China and Brazil. (iii) Alexandrite is obtained from Ceylon, Ural mountains and Tasmania. Perfectly clear and colourless crystals are sometimes obtained from the Ruby Mines of Upper Burma. But most of the gem quality came from Ceylon as water-worn pebbles in alluvial deposits. Both Alexandrite and cat's eye are obtained in Ceylon from the 'Illam' or the gravel from which the gems are obtained.

In India, chrysoberyl has been found in Coimbatore district, at Kangayam, with deep blue apatite in felspar-corundum rocks, but the stones are flawed and not suitable for gem-stones. In Kishengarh, yellow crystals of good quality occur in the mica-pegmatites. Some small crystals have also been found in a vein in granite in the Cuttack district, Orissa.

## INDUSTRY

Chrysoberyl is obtained from the gem areas of Ceylon and Burma along with rubies and sapphire, and are also sold with other stones.

## CELEBRATED CAT'S EYES

The largest cat's eye (also the 'Hope') is hemispherical and half inch in diameter. It was in the possession of the King of Kandy (Ceylon) from whom it was captured in 1815. It has been known from the sixteenth century. It is mounted in massive pure gold and set with rubies in the eastern fashion. There was another cat's eye once with Pundit Lutchminarain, which he sold for Rs.6,000. Another large gem of a pigeon's egg size was also known to be in the Tagore family.

## CHAPTER XV

### BERYL

#### INTRODUCTION

BERYL has been known from ancient times, but the name was applied to a variety of stones, and its correct use came into vogue only about the end of the eighteenth century, because beryllium was discovered only in 1798 and the metal extracted in 1828. The metal is very light, but hard and silver-white. There is a great demand for beryllium for making light alloys for construction of aeroplanes, which has, in turn, created a great demand for beryl since the war started.

#### PHYSICAL PROPERTIES

Beryl is an alumino-silicate and includes the emerald aquamarine, golden beryl and morganite. Crystals of beryl form well-shaped hexagonal prisms terminated by basal planes. Sometimes they form enormous crystals weighing even a few tons. But such crystals are coarse and opaque and are of no value as gems, but form the ore of beryllium. The faces are striated parallel to its length. Common beryl is dull and opaque and is pale green or yellow in colour. Gem qualities—emerald is grass-green, but stones with such colours as pale green, yellowish green, bluish green to deep blue are called aquamarine. Specific gravity = 2.62 to 2.9 according to variation in composition. Hardness =  $7\frac{1}{2}$  to 8. Fracture: conchoidal to uneven. Lustre: Vitreous. Refractive index:  $\omega = 1.57$  to 1.60;  $\epsilon = 1.56$  to 1.59. Dichroism distinct, but not strong. Uniaxial and negative. Composition:  $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$ . Beryllium is replaced by alkalies, lithium, sodium, potassium and caesium.

#### USES

Ordinary beryl is not useful as a gem-stone, but is useful for the extraction of beryllium, which is an extra-

ordinarily light, yet hard and silver-white metal. With aluminium, it produces an alloy which is hard, strong and light material for the construction of aeroplanes and airships. The transparent and coloured varieties, e.g. emerald, and aquamarine form valuable gem-stones. Precious beryl and aquamarine show well in artificial light.

### GRADES

Beryl proper commands very little value as a gem-stone. But the coloured and transparent varieties, e.g. emerald and aquamarine form valuable gem-stones. Because of its rich colour and the rarity of fine quality material, emerald is the costliest gem-stone. Its refractivity and dispersion are weak. It has neither brilliancy nor fire. The green colour is due to chromium. Aquamarine is transparent, and its colour varies from pale blue to sea-green. Heat treatment is said to improve the colour of these stones. When pure it is of a golden-yellow colour and it is then known as golden beryl.

The emerald has been known amongst the Hindus as 'Marakata' and as coming from the Black Sea coast. It was also known in Europe at the time. They considered genuine emeralds as infallible remedies for all cases of poisoning. These stones are also divided into four castes, each being recognized by certain peculiarities of shade and other marks. The green colour of the emerald was considered to be due to chromium, but is also believed to be due to some organic substance, perhaps abstracted from its matrix, which contained organic remains. The Tagore family and other notables are said to possess good specimens of emerald. Heliodor is a variety of yellow beryl from south-west Africa. Morganite, also known as Vorobievite, is a pink or rose-red beryl. Flawless emeralds of good colour are extremely rare and are very valuable. Owing to inclusions they have a massive appearance. Emerald

is cut step or brilliant, and dark stones en cabochon. Aquamarine is cut in pendant shapes.

#### OCCURRENCE

Gem varieties of beryl have been found in several places. Emeralds of fine quality came from Muzo and Chivor in Colombia, Bahia in Brazil, from Ural mountains, from Australia and North Carolina. Aquamarine has been found in Brazil, Island of Elba, from Madagascar, from the Mourne mountains of Ireland, etc. Golden beryl is found in Bahia, Brazil. Beryl is generally found in pegmatites. Emerald has been found in mica-schist and in dolomite marble in Brazil.

*India.*—Beryl has been found in the mica-pegmatite of Nellore and Bihar, Rajputana and Kashmir. In Madras it has been found in Pattalai (Coimbatore district) at a contact of gneiss and mica-schist, being a blue or sea-green variety (aquamarine). In Mysore it has been found at Melkote—a yellow green aquamarine in pegmatite. In Rajputana (Ajmer) a green beryl is found in Banas at Rajmal and at Kishengarh—aquamarine. Beryl is mined in Rajputana on a large scale and exported for use in the preparation of metallic beryllium and its alloys.

*Kashmir.*—Beryl and aquamarine are found in Kashmir at Daso, Baltistan, where a deposit was worked in 1917. Good stones were sold at 5s. per carat at the Wembley exhibition. It occurs in pegmatite associated with sapphires near Soomjam, Danjal,  $1\frac{1}{2}$  miles N.E. of Kabon, 2 miles north-west-by-north of Hamur and 1 mile west-by-south of Chishote.

#### EMERALDS IN MEWAR.

(H. Crookshank—*Indian Minerals* (1947), pp. 28–30.)

During the war an extensive search was made for beryl in Rajputana. In this attempt some green crystals were obtained from Mewar, which were found to be as good as the Russian emeralds which were being sent to Jaipur for

cutting. Sir Bhagchand Soni on the advice of Mr. Crookshank took up a mining lease for emeralds in Kaliguman area, where the emeralds were found. The venture was crowned with success and a very large number of emerald crystals varying in size from  $\frac{1}{2}$  inch to 4 inches in length with diameters up to  $1\frac{1}{4}$  inches were extracted. The Mewar Government took over the crystals for safe keeping pending their ultimate sale by auction. Some months after the work was started, half the crystals fetched about Rs.2,69,000.

The mine is situated at Kaliguman, a small village between Amet and the famous old fortress of Kumalgarh, some 13 miles from the station. The mine is well guarded and visitors are not usually allowed within the precincts.

The mine is located within bands of biotite rock intercalated in the normal hornblende-schist. It is about 100 yds. long and 60 feet deep. The emeralds occur through the biotite much like garnet or andalusite in similar rocks. The origin is considered to be due to a pegmatite intrusion.

Seth Banjilal Thulia, an emerald merchant at Jaipur, cut the Kaliguman beryls and showed that their colour was exquisite, water perfect; but expert jewellers say that they are not so clear as the Potosi emeralds. The price is said to be about Rs.2,000 a carat. But a majority of the stones have been found to be defective.

*Ceylon.*—Aquamarine and other gem-stones occur in the gem-gravels of Ceylon in alluvial deposits and also in a matrix of pegmatite.

*Burma.*—In Mogok stone tract, beryl has been found in the *byon* or the gem-gravels and in the once famous Sakangyi dyke—now no longer working.

## INDUSTRY

The emerald takes its rank with the ruby as one of the most valuable gem-stones. Flawless emeralds are extremely rare and command very high prices. A good

emerald costs as much as a ruby and more than a diamond. One carat stone costs £20. The stones are cut brilliant, but the step form is more common. The dark stones are cut en cabochon and engraved. Aquamarine is also cut in pendant-shaped forms.

Synthetic spinel is often sold improperly as aquamarine. Doublets, triplets and glass imitations have also been made. Cut beryl and topaz look very much alike and may easily be mistaken for one another. But specific gravity, hardness and refractive index help to identify them correctly.

## CHAPTER XVI

### TOPAZ

#### INTRODUCTION

Formerly the name 'topaz' was very loosely used to denote a number of yellow stones. So yellow sapphire was known as 'oriental topaz', 'Scotch topaz', 'false topaz', and 'Madeira topaz'; smoky topaz for citrine and smoky quartz. Such use of terms leads to much confusion and should be entirely avoided. Real topaz ranks with beryl as a gem-stone.

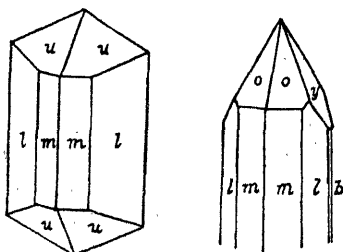


FIG. 39.

Topaz crystallizes in the orthorhombic system with predominating prismatic forms. The prism faces ( $lmm$ )

are striated parallel to the vertical axis of the crystal. Usually one end of the crystal is terminated, the other being a cleavage plane and the crystals grow on one end attached to the matrix. Other faces present are the pyramid and the domes. The appearance of the crystals becomes different due to variation in relative sizes of these faces, but the interfacial angles and directions of edges are constant. Topaz also occurs in compact and granular masses and water-worn crystals. The basal cleavage is parallel to the basal pinacoid and is an important character. It is also seen by well-defined cracks. This has to be considered when cutting topaz. The fracture is conchoidal to uneven. Topaz is clear and colourless, but may at times be coloured. Colours may vary from wine yellow, brownish, grey and pale tints of blue to green, violet and red. Pale blue topaz is common, but green, red and pink are rare. Crystals of a sherry yellow colour are known only from a single locality in Brazil—Brazilian topaz—most of the Brazilian topaz is colourless or blue. The yellow topaz is of gem variety. Lustre: Vitreous. Specific gravity = 3.4 to 3.6. Hardness = 8. Refractive index:  $\alpha = 1.61$  to  $1.63$  and  $\gamma = 1.62$  to  $1.64$ . Double refraction is 0.010. Dispersion is 0.014. Biaxial and positive. Composition: It is a fluosilicate of aluminium  $\text{Al}(\text{FO}_2\text{H})\text{SiO}_4$ . Fluorine content varies from 20.6% to 15.5%.

On account of its hardness, it takes a good polish and shows a brilliant lustre which is often seen on the crystal faces.

#### GRADES

- (1) The Brazilian topaz has a sherry yellow colour and is of gem quality, but much of it is also of pale blue colour.
- (2) Crystals of a brownish yellow shade occur in Siberia, Utah and Colorado, but they fade on exposure to light.
- (3) Ceylon topaz is colourless but is confused with yellow sapphire as 'oriental topaz'.



## USES

The yellow and colourless precious topaz is most often used as a gem. It is cut in brilliant form in Mogok and is called 'Mogok diamond'. In India it has been called 'Pushparagam'. The step cut is used at times—all specimens sufficiently transparent, finely coloured and free from faults are used as gems. Inferior stones are crushed and powdered for use as grinding material.

## OCCURRENCE

Gem topaz is largely obtained from Brazil. It is found in the Ural mountains and Miask, the Ilmen mountains. Blue topaz has been obtained from Caingorm, Banffshire, Scotland and a few other places. Good crystals also occur in the tin mines of Saxony and Cornwall; and in Ceylon, Japan, Mexico and Tasmania.

It usually occurs in gneisses, schists, granites and pegmatites, and is usually the product of pneumatolysis by the action of gases containing fluorine and watery vapour from igneous intrusions, often accompanied by beryl and cassiterite. Topaz as a gem-stone was known in India from very ancient times. It is found in the Tavoy district, Burma along with tin and wolfram in mines. At times pellucid water-worn crystals of topaz are found in the gem-gravels of Mogok. Very fine specimens of topaz were obtained from the great pegmatite dyke of Sakangyi in the Mogok Stone tract. There was extensive mining in this area about 1923 for rock crystals; along with it the topaz crystals were also obtained. Exceptionally large crystals were obtained here. In Mogok it forms a cheap stone, and is sold as Mogok diamonds. Its usual associates are tourmaline, quartz, fluorite, apatite, beryl and other ores of tungsten. It also occurs in placer deposits. In Ceylon it forms colourless water-worn pebbles.

## INDUSTRY AND MARKETING

Topaz is not considered a very costly gem-stone and could be had fairly cheap, but 'coloured varieties command higher prices. Brazil is the most important place for gem topaz and next come the Ural mountains.

Amongst the ancients, like the ruby, the topaz was also supposed to be gifted with marvellous medical properties, and also believed to be capable of giving light in the dark. When powdered and taken in wine, it was considered a cure for asthma, sleeplessness and many other diseases.

### CELEBRATED TOPAZES

Tavernier saw in the treasury of Aurungzebe one topaz crystal when he had the audience of the Emperor in 1665. It weighed  $157\frac{3}{4}$  carats and was of an octagonal shape. It is said to have been purchased for Rs.1,80,000 at Goa. The Braganza, supposed to be a celebrated diamond, is now considered a topaz. One topaz crystal  $4\frac{1}{2}'' \times 4\frac{3}{4}''$  which weighed 31 pounds was at St. Petersburg. There is also a big lump of topaz, which served once as a door-knob, and later was discovered to be a topaz. A few good stones are also found with the Tagore family.

## CHAPTER XVII

### GARNET

#### INTRODUCTION

GARNET is the name given to a group of minerals, having a close relationship or form or known as an isomorphous series. It is a group of important rock forming minerals. The garnets possess bright colours and lustre to qualify them as precious stones, but they are so common that they could never rank as a precious stone. They are also very cheap. All the varieties of garnet crystallize in the cubic system with very similar forms. The rhombic dodecahedron and icositetrahedron occur either alone or in

combination. It also forms compact granular aggregates, rounded grains and water-worn pebbles. It has an imperfect dodecahedral cleavage. Fracture: Conchoidal to uneven. Hardness =  $6\frac{1}{2}$  to  $7\frac{1}{2}$ . Specific gravity = 3.4 to 4.3 depending upon the composition. Colours vary. All colours except blue are met with, e.g. red, brown, yellow, green and black are the more common colours and also colourless. The colours are due to the elements that enter into the composition of the minerals of the group, and also due to impurities present in small amounts. The colourless garnets may be transparent to translucent, whereas the dark coloured varieties are translucent to opaque. Lustre is vitreous to resinous. Refractive index of gem garnets vary from 1.70 to 1.94, and the dispersion ranges from 0.024 to 0.028, but in one instance andradite goes up to 0.057, which is comparable with that of diamond. When the colour is not dark, the garnets have considerable brilliancy and fire. Garnets are isotropic and have no dichroism—this fact enables rubies to be distinguished from garnet, although refractive index and specific gravity may be more or less of the same order.

### COMPOSITION

For the whole group, the generalized formula  $M'_3M''_2(\text{SiO}_4)_3$ , in which  $M'$  represents the bivalent elements Mg, Ca, Mn, or Fe and  $M''$  for trivalent elements as alumina, ferric iron or chromium. Six varieties of garnets have been identified and also their physical and chemical properties. Their composition grades one into the other, and so also the physical and chemical properties.

<i>Garnet Species</i>		<i>Chem. Comp.</i>	<i>Ref. Ind.</i>	<i>Sp. Gr.</i>
1. Grossularite	..	$\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$	1.735-1.763	3.4-3.7
2. Pyrope	..	$\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$	1.705-1.760	3.7-3.8
3. Spessartite	..	$\text{Mn}_3\text{Al}_2(\text{SiO}_4)_3$	1.794-1.814	4.0-4.3
4. Almandine	..	$\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$	1.766-1.830	3.9-4.2
5. Uvarovite	..	$\text{Ca}_3\text{Cr}_2(\text{SiO}_4)_3$	1.838	3.4-3.5
6. Andradite	..	$\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_3$	1.865-1.940	3.8-3.9

## USES

The light coloured and flawless garnets are used as cheap gems and the rest for abrasives. Garnet in the form of powder is a valuable grinding agent for precious stones and is used in making emery paper. It is also used for making pivot support of watches, etc.

## GRADES

1. *Grossularite*, hessonite or cinnamon stone is the calcium garnet, which is reddish yellow in colour and contains three to four per cent of iron oxide. It is lighter coloured than the other varieties or may even be colourless. Various shades of yellow and brown are met with. The terms 'hyacinth' and 'jacinth', applicable to a zircon have been wrongly used.

2. *Pyrope*.—It is the best known of the gem garnets because of its beautiful ruby red colour. It occurs with the diamond in South Africa, and is sold as Cape ruby. It is cut in a faceted form and is sold as 'Bohemian garnet', 'Cape ruby', 'Elie ruby', etc. It occurs in grains and as stream pebbles and not in good crystals. The colour varies from deep red to black.

3. *Spessartite*.—It is not much used in jewellery, as its colour (brown) is not popular. The colour may also vary from brownish red to a dark red with a tinge of violet.

4. *Almandine*.—It was known to the ancients and called by them 'Carbunculus'. Its colour varies from deep red to violet red and to black, but most of it is dark and opaque and is used for abrasives. The transparent varieties are used as gems. In artificial light it shows an orange hue. It can be distinguished from red spinel by the pocket spectroscope. Facetted and hollow cabochon forms are cut, which give a more attractive colour; large quantities are being produced at Jaipur and Delhi. On some carbuncles an interesting type of asterism may be noticed.

5. *Uvarovite*.—It is emerald green due to chromium and forms small crystals with chromite. The crystals are too small to be of value as gems.

6. *Andradite*.—It has a varying composition and a variety of colours. (a) Topazolite is transparent yellow and resembles topaz. (b) Demantoid is grass-green. It has a high refractive index and dispersion greater than that of diamond, and a faceted stone flashes brilliant prismatic colours. (c) Melanite is the black variety. It has a very high refractive index.

### OCCURRENCE

Grossularite occurs in metamorphosed impure limestone, and hessonite comes from Ceylon in gravels associated with zircon. Pyrope occurs in the diamondiferous rock in South Africa, and usually occurs in basic rocks, such as peridotite and in serpentine. Spessartite occurs in granite, quartzite, etc., in Ceylon, Madagascar and some other places and is also associated with manganese ores. Almandine occurs in gneisses, schists and a variety of rocks. The gem quality is found in India, and Ceylon in gravels; South Australia; Minas Geraes, Brazil; Uruguay; various parts of U.S.A., etc. Uvarovite is obtained principally from the Ural mountains and in Quebec. Andradite occurs in nepheline-syenite, serpentine, chlorite-schist, crystalline limestone and stream beds.

In India, garnet is found in a large number of places, but gem garnets occur only in a few localities. In Bihar and Orissa, garnet is found in the sands of the Mahanadi river. In Hazaribagh large garnets are found in the mica pegmatites and small ones in schists which are not of gem quality. In Hyderabad, near Warangal, garnet occurs in gneiss. Some gem quality garnet is also obtained which is largely used in Madras for jewellery. In Madras garnet is found at Kondapalli in Kistna district at Bezwada on the banks of the Kistna river; red garnets are obtained in the

crystalline and metamorphic rocks in the Nellore district; near Sankaridrug, Salem district; near Konibetta in the Nilgiris. Brownish red to deep red or pink garnets are obtained near Mel Amathur, Tinneveli district and small garnets of a rich colour are obtained in Travancore.

Rajputana has garnet mines along the outcrops of the Aravalli schists, which are traversed by granites and between the Udaipur and Jaipur States. A large trade once existed between the mines and Delhi. Garnet is also obtained at Ajmer, Jaipur, Kishengarh and Shahpura. The Kishengarh garnets are said to be the finest in India. Ceylon also produces a lot of almandine or gem garnets.

### INDUSTRY

Rajputana garnets are often of gem quality and are mined intermittently. The stones are cut in Jaipur and Delhi, where gem-cutting forms an important industry. A portion is also exported and goes to London. The Warangal garnets were sent to Madras and also to Europe. Tinneveli garnets are mostly used for abrasives.

### MARKETING AND FUTURE TREND

Gem garnets form cheap precious stones and can always find a fair market. The inferior garnets could find a market when the indigenous abrasive industry is gradually developed.

## CHAPTER XVIII

### TOURMALINE

#### INTRODUCTION

TOURMALINE is a boroalumino-silicate of very complex composition. It crystallizes in the rhombohedral-hemimorphic system being different at the two ends of the crystals. The crystals form curved triangular prisms. The

prism faces are also deeply grooved parallel to the vertical axis. The vertical axis is polar—different crystal forms are present at opposite ends—one termination is more obtuse than the other. Two sets of prism faces occur—hexagonal prism and a trigonal prism, and terminated by trigonal pyramids, and also rhombohedral faces. It also forms compact or disseminated masses and divergent aggregates.

It has a rounded triangular outline. Cleavage—not well-developed. Fracture is sub-conchoidal to uneven. Hardness = 7 to  $7\frac{1}{2}$ , not hard enough to be used in rings, but good enough for being used in brooches, pins, etc. Gem tourmaline has a mean refractive index of 1.63, double refraction 0.020 and dispersion 0.016. It shows a wide range of colours—from colourless to jet black and opaque; it may also show bright colours as red, yellow, brown, green or indigo-blue. One and the same crystal may show different colours. Zonal arrangement of colours may also be found, e.g. parallel to the prism faces. Tourmaline has also strong pleochroism or dichroism. In dark crystals the ordinary ray is completely absorbed and the extraordinary ray is allowed to pass. So a basal section is dark, whereas a section cut parallel to the vertical axis will show some transmitted light and colour. Two such slices cut parallel to the vertical axis could make a polarizing apparatus, 'tourmaline tongs'. When the slices are held parallel, light is allowed to pass and when in crossed position, light is cut out. On account of this property, in cutting the table, facet has to be parallel to prism faces. It has also the property of developing pyroelectricity or piezo-electricity due to its hemimorphic development. When a crystal of tourmaline is changing in temperature, one end develops positive electricity and the other end develops negative electricity. When pressure is applied in the direction of elongation, a charge of piezo-electricity is also developed. This property is taken advantage of for

registering small variations in pressure, and is useful in the estimation of depth of submarines and the tourmaline is more valuable for this property than as a precious stone.

Composition is approximately (Mg, Fe, Mn, Ca, Na, K, Li, H)  $\text{Al}_2\text{B}_2\text{Si}_4\text{O}_{21}$ . Sub-species could not be determined by composition as in garnet, although chemical analysis may help to divide into iron-tourmaline, magnesia-tourmaline, lithia-tourmaline, etc., but classification has been based on colour.

### USES

Gem tourmaline is usually cut with the table parallel to the vertical axis, which shows the dichroism and a pleasing variation in colour. It is appreciated as a good stone for pendants, brooches, etc. The piezo-electric property of tourmaline has already been referred to.

### GRADES

Gem tourmaline is appreciated as a good stone for pendants, brooches, etc.

As already mentioned, tourmaline may be divided into iron-, magnesia-, and lithia-tourmalines.

The usual names based on colour for the gem varieties are as follows:—

1. Achroite—colourless.
2. Shorl—black.
3. Rubellite—red.
4. Indicolite—indigo-blue.

They are also called 'Brazilian ruby', 'Brazilian emerald', and 'Brazilian sapphirine'; these terms are misleading and should be dropped. The colours should be mentioned along with the tourmaline. By heat treatment some tourmaline could be improved. Tourmaline, rich in alkalis, is transparent and has the most attractive colours.



## OCCURRENCE

Tourmaline is found in igneous and metamorphic rocks of various kinds and in veins of tin ore, and also in gem gravels in Ceylon. It occurs in mica-schists, marble and pegmatites. The gem varieties occur in pegmatites, and are associated with quartz, beryl, apatite, topaz and fluorite. Tourmaline also occurs in numerous places. The island of Elba is famous for many coloured and zoned tourmalines. The first stones used in Europe were from Ceylon. Other localities are India, Burma, Siberia and Brazil. There are also a few localities in the U.S.A. Most of the occurrences of tourmaline in India are black and non-precious. Large tourmaline crystals occur in the Bihar mica belt both in the pegmatite and the schists. Tourmaline is found in Burma in Karenni, Mongmit, rubellite in the Ruby Mines and Mong Long in Northern Shan States recorded by Barrington Brown and Judd. In India the gem variety occurs at Padar in Kashmir, and in some places in Nepal. In Burma red and black tourmaline are found as water-worn pebbles in the sands of the Nampai valley, near Namseka village, and the material mined used to be sent to China.

## CHAPTER XIX

### ZIRCON

#### INTRODUCTION

ZIRCON was known from ancient times in India as 'Gomeda' and was also divided into four classes like the diamond. It comes next to diamond in brilliancy and fire, and ought to be a popular stone, but it is not even well known. There are many anomalies of the mineral which remain yet unsolved. It is known as 'Gomeda' among the Hindus and as hyacinth or jacinth among the Greeks.

It crystallizes in the tetragonal system, is prismatic in habit and has pyramidal terminations. It may be combined with one or other or both of the square prisms *m* and *a* which are at  $45^\circ$ . Cleavage is prismatic and pyramidal, but imperfect. Fracture: Conchoidal. Specific gravity = 4.0 to 4.80. Hardness =  $7\frac{1}{2}$ . Colour: Brown, brownish red and gray, and is due to iron and other constituents. Transparent to opaque and has adamantine lustre. Refractive index = 1.8 to 2.0, more than that of corundum and less than that of diamond. Double refraction is 0.06, and dispersion 0.048. Uniaxial and positive. Impurities are iron and hafnium. Composition:  $\text{ZrSiO}_4$ .

Some zircons show some anomalous properties; for instance, some crystals are biaxial, some are uniaxial and some isotropic. These three characters may be shown by different portions of the same crystal, with sometimes division into separate zones. Colours show a wide range and are liable to change on exposure to sunlight, heat, X-rays, etc. Some zircons change colour on heating or may be completely decolourized. Much of the colourless zircon used as gems has been so treated; with its brilliant lustre and high dispersion it resembles diamond to some extent and is known as 'Matura diamond', from Matura in Ceylon. The sky-blue zircon may also be heat treated.

Zircon has also been divided into three qualities. *A* zircon: sp. gr. = 4.0; refractive index = 1.80 to 1.89; and birefringence 0.01. *B* zircon: sp. gr. = 4.70; refractive index = 1.92 to 1.99; and birefringence = 0.05 to 0.06. These two zircons are not changed when heated. *r* zircon, which has values intermediate between those of *A* and *B* zircons, when heated change into *B* zircon. All these forms may form part of the same crystal.

### USES

Some of the colourless and coloured varieties are used as gem-stones. When subjected to heat treatment, they

become colourless and due to their lustre, they are known as 'Matura diamonds' from Ceylon. Zircon is also used for the manufacture of zirconium oxide, a highly refractive material suitable for crucibles, etc., and for preparation of metallic zirconium.

#### GEM VARIETIES

1. Hyacinth and jacinth—clear, transparent, yellow, orange, red and brown—formerly also applied to blue stones.
2. Jargon includes other colours.
3. Matura diamond is zircon from Matura, Ceylon. It is naturally colourless or rendered colourless by heat treatment.
4. Blue zircon is getting popular in recent times.

#### OCCURRENCE

Zircon is a common accessory mineral occurring in many granites and gneisses. It occurs in Travancore in some coastal sands (zircon sand). Gem quality stones are found as pebbles and water-worn crystals in alluvial deposits in Ceylon, Siam and Indo-China. Ceylon and Indo-China are the most important localities for gem zircon, which also occurs in Tasmania, New South Wales and New Zealand. Blue zircon is found in Indo-China.

The Ruby Mines of Burma also produce some transparent brown zircons. Pale or straw-yellow and colourless zircons come from Ceylon and are cut as gems. It also occurs in small quantities in nepheline syenite near Kangayam, Coimbatore district, and in Travancore in pegmatite veins associated with charnockite in Eraniel taluk, in pegmatites in Kadavur, Trichinopoly district; and in the Seitur graphite mine, Ramnad, Madras Presidency; and near Domchanch, Hazaribagh district. Some dark brown crystals were also obtained from Abraki Pahar, Gaya district, Bihar.

## INDUSTRY AND MARKETING

Zircon is recovered from the Travancore beach sands by the Travancore Minerals Co., Ltd., and is exported to U.K., Germany, U.S.A. and Austria for industrial purposes. The sands here contain 6% of zircon. It occurs only rarely in large amounts. The largest crystal on record weighed 15 lb. which is exceptional.

## CHAPTER XX

### OLIVINE OR PERIDOTE

#### INTRODUCTION

IT is an important rock-forming mineral and is widely known. Olivine is known to the jewellers as 'peridot' and 'chrysolite'. The term olivine is also improperly used for green garnet and other green stones. It crystallizes in the orthorhombic system and may occur as crystals or grains. The cleavage is pinacoidal in two directions. Fracture is conchoidal. Specific gravity = 3.2 to 3.4 or even higher. Hardness =  $6\frac{1}{2}$  to 7 (not high enough for a gem). Colour: Various shades of green, yellow, brown, reddish, etc. The best colour is a beautiful bottle green. Peridot is olive-green. Lustre: Vitreous to greasy; transparent to translucent. Olivine is biaxial and optically positive. Mean refractive index = 1.66 to 1.68. Double refraction = 0.04 (high). The dispersion is 0.018. Composition:  $Mg_2SiO_4$ - $Fe_2SiO_4$ . Intermediate varieties are called olivine.

#### USES

Peridot has a bottle green colour and is used for gems. Its hardness is 6, and being less than that of quartz, the mineral is subject to quick wear. Hence it is not suitable for rings. The stones are usually cut brilliant or step, but the cabochon is sometimes used.

## OCCURRENCE

Olivine forms the main constituent of peridotites, and also occurs in basalts and in crystalline limestone. The gem quality olivine is also found in meteorites. In Burma, it is found in the Ruby Mines area near Bernardmyo, where there are a number of exposures of peridotite. Griesback mentions its occurrence in Afghanistan in a basalt. But most of the gem quality stones come from the island of St. John, off the coast of Egypt in the Red Sea. Other localities for gem peridotite are Burma, Ceylon, Queensland, Brazil and New Mexico.

## INDUSTRY

Some small scale mining is done near Bernardmyo, Burma, and the stones are sold locally along with other semi-precious stones in Mogok. It sells for a rupee per carat.

## CHAPTER XXI

### QUARTZ

#### INTRODUCTION

QUARTZ is one of the most abundant minerals and the most common. It has many varieties, which could be utilized for ornamental purposes. It occurs in every type of rock, e.g. igneous, sedimentary or metamorphic, and has both crystalline and amorphous forms with many attractive varieties. It is one of the most important semi-precious stones. It is found in rocks of all geological ages. It also fills cracks and crevices and is the most important constituent of sands and gravels. It has also been known from very ancient times. Flint, one of its varieties, was known to primitive man, who made implements out of it and also knew to produce sparks and then light his fire.

Quartz crystallizes in the hexagonal system in good prismatic crystals, the faces being horizontally striated and

has pyramidal terminations. Crystals are rhombohedral. They may be right-handed or left-handed forms due to tetrahedral symmetry. Two independent rhombohedra combine to give a hexagonal pyramid, but the faces differ in size, three smaller faces alternating with three larger faces; this is characteristic even in very small crystals. Twins are also found, as also irregular puzzling growths, which could be oriented and deciphered by the horizontal striations on the prism faces. The crystals vary enormously in size.

Quartz contains various inclusions: (a) solid inclusions of rutile, hematite, epidote, etc.; (b) liquids, e.g. water and liquid  $\text{CO}_2$ ; and (c) gaseous inclusions, mostly  $\text{CO}_2$ . It has conchoidal fracture. Hardness = 7. Specific gravity = 2.66 in pure quartz, varying from 2.5 to 2.8 in other varieties. Lustre: Vitreous. Transparent to translucent or opaque. Uniaxial. Optically positive. Mean index of refraction = 1.55, double refraction = 0.009 and dispersion = 0.013 (low). It is optically active and rotates the plane of polarization to right or left according as it is a right- or left-handed crystal. Composition:  $\text{SiO}_2$ . Quartz may be very pure or contain mineral inclusions and other foreign matter. Also forms pseudomorphs, e.g. fossil wood. It is a fairly resistant mineral, but may be replaced by other minerals.

### USES

Crystalline and crypto-crystalline varieties of quartz are used for gem purposes. The crystalline quartz is cut in faceted forms or cabochon. Rock crystals are also cut into vases, crystal balls, idols, etc. When cut it resembles beryl and topaz. On account of its piezoelectric properties, properly oriented sections are used in radio apparatus as resonators and oscillators in radio-telephony and radiotelegraphy and for depth measurements in submarines.

## GRADES—VARIETIES OF QUARTZ

The varieties include crystalline, crypto-crystalline, and clastic and the gem varieties belong to the first two classes. Another classification is transparent, translucent and opaque. The cost of cutting governs the value of gem quartz.

### 1. *Crystalline varieties*

(i) *Crystalline varieties*.—Rock crystal—pure, transparent, water clear and well crystallized. It is used for vases, beads, crystal balls, etc., and has enjoyed great popularity.

(ii) *Amethyst*.—Purple or violet—transparent and well crystallized. Colour varies in intensity or may be unevenly distributed. Heat treatment may improve the colour.

(iii) *Rose quartz*.—It is invariably massive, transparent to translucent with a greasy lustre and milky appearance. It may also show asterism, which is best seen in transmitted light—may be cut cabochon, etc.

(iv) *Smoky quartz*.—Cairngorm—smoky yellow to dark brown and black. It may be decolorized by heat. It is slightly dichroic, and is used for brooches, pins and other ornaments.

(v) *Tiger's eye*.—Pseudomorphous after crocidolite and chatoyant when cut en cabochon.

(vi) *Cat's eye*.—It has parallel fibres of asbestos and is greyish, brownish or green in colour. When cut en cabochon, it shows a chatoyant band of reflected light on the surface.

Other varieties include citrine or yellow quartz, milky quartz—transparent and opaque, saphirine quartz—indigo blue, aventurine quartz with scales of bright coloured minerals, and sagenite with hairlike rutile inclusions.

### 2. *Crypto-crystalline varieties*

(i) *Chalcedony*.—Transparent and translucent and includes several varieties: (a) *Carnelian*—reddish; (b) *Chrysoprase*—

apple-green; (c) Phrase—translucent and leek green; (d) Plasma—some shades of green, often of a dark green colour—stalactitic or concretionary forms as linings of cavities—light-coloured, white, grey or brown or blue form of quartz with a waxy lustre. Chalcedony is cut cabochon.

(ii) *Heliotrope or bloodstone*.—A dark green chalcedony containing scattered spots of red jasper—used for engraved objects and signet rings.

(iii) *Agate*

It is a very popular and crypto-crystalline variety of quartz and occurs in geodes of volcanic and sedimentary rocks and as pebbles. The colours are dispersed in parallel bands, which are more or less wavy. Colour—white, brown, red, blue, etc. Agate may be pseudomorphous after wood. Idar-Oberstein is the place in Germany for cutting and polishing agate. Agate is also artificially coloured.

(iv) *Onyx*

Similar to agate, with coloured bands straight and parallel. It is used for cameos.

(v) *Jasper*

Opaque, red, yellow, brown, dark green or greyish blue. When the colours occur in broad bands or stripes, it is called riband jasper.

(vi) *Flint*

Transparent to opaque, grey, smoky brown or black, used by early man to make weapons and also fire. It is found in chalk and has a white coating.

## OCCURRENCE

Rock crystal is a very common gem mineral found in veins in metamorphic rocks and in pegmatite dykes. It is obtained from Japan, Brazil, Madagascar, Switzerland, New York and Arkansas. The main supply for optical purposes



is from Brazil and Madagascar. Cavities containing liquid with a movable bubble are sometimes present.

Amethyst is obtained from Brazil, Ceylon, India, Madagascar, Persia, Mexico, Maine, Pennsylvania, Carolina and Lake Superior districts. Material of gem quality is obtained in the gem gravels of Ceylon. Rose quartz is obtained from Japan, Madagascar, Bavaria, France, Brazil, etc. Smoky quartz comes from Ceylon, Alps, Cairngorm, Scotland, etc. Citrine comes from Brazil.

*India.*—Rock crystals have been obtained from several localities. Rose quartz is obtained in Sambalpur in Orissa as well as rock crystals. In Bombay rock crystal is obtained from Tankara, and taken by the lapidaries of Cambay. In Central Provinces, it is obtained from Chindwara and at Warangal in Hyderabad. In Madras it occurs in Godavari near Rajahmundry and at Tanjore, where it is called the 'Vallam' diamond, and also smoky quartz and Cairngorm derived from a conglomerate. Rose quartz occurs in Vizagapatam. In the Punjab it occurs at Delhi, from Delhi quartzite and from Mianwalli called 'Mari diamonds'. It is collected and drilled to be made into necklaces. Amethyst occurs in Bihar, in Santal Parganas in a bed of chalcedony two miles west of Burhait ( $24^{\circ} 53'$  :  $87^{\circ} 40'$ ) and in the Central Provinces small crystals in the Deccan Trap geodes.

#### OTHER VARIETIES

*Agate varieties.*—Carnelian, onyx, etc., are found in lavas of amygdaloidal flows of Deccan and Rajmahal traps, the sources being the rivers that drain the areas covered by the rocks in Kistna, Godavari and Bhima rivers—Jubbulpore. In Bihar, Rajmahal hills, 2 miles north of Burhait, a bed of agate is present in the centre of the hills for 1 to 2 miles.

*Bombay.*—Agate is worked at Cambay, and obtained from Ahmedabad, Kaira and Kathiawar (moss agate).

Rewa Kantha produces carnelian and agate. Carnelian is also obtained from Rajpipla.

*Madras*.—Godavary river, near Rajahmundry—agate, jasper and carnelian pebbles.

*Onyx*.—Occurs in Bombay in Nawanagar in bedded lavas.

*Industry and marketing, etc.*—The most important and well-known place where agate and carnelian are cut and prepared for market is Cambay, in the Bombay Presidency. Other centres for agate cutting are at Jubbulpore, C.P., Banda in the U.P. and at a few minor places within the range of the Deccan trap. Cambay also supplies most of the agate supplied in Europe. Large quantities are also exported to China.

The crystalline varieties, rock crystal, amethyst, etc., find their use in jewellery in several parts of India, as for instance in Tanjore 'Vallam diamonds', near Kalabagh and Mari—'Mari diamonds', and also in Kashmir. In N.W. India, rock crystals are also cut into cups, trinkets, ornamental objects and sacred objects like lingams, etc.

*Opal*.—The opal was regarded as a very precious stone by the ancients, and it was next in rank to emerald. It was not popular for some time, but is now getting popular. The finer varieties are very highly valued. It is amorphous and has no crystal form. It consists of silica like quartz but contains water in addition. It is a dried up silica jelly. It forms compact and irregular masses in veins and cavities. Fracture conchoidal. Hardness =  $5\frac{1}{2}$  to  $6\frac{1}{2}$  and is comparatively soft. Specific gravity = 1.95 to 2.30. It wears quickly but could be repolished. Lustre: Vitreous, dull or greasy, and transparent to opaque. Colour varies greatly, being white, yellow, brown, red, pink, green, grey or black. Precious varieties have a play of colours due to the interference of light. (See Spencer, pp. 202-203.) It is formed from gelatinous silica, and is deposited in cracks and cavities. Refractive index = 1.44.

Isotropic Composition  $\text{SiO}_2.x\text{H}_2\text{O}$  (contains 3–10% of water). Impurities also occur, e.g. calcium, iron, magnesium, etc.

*Grades.*—Precious opal has a number of varieties. It has a delightful play of colours, and is cut cabochon to show the property best. The precious varieties have their own names, e.g. white opals, having a light colour; black opal—colour varies from dark grey to blue and black types—a valuable variety; harlequin opal contains patches of colour. Fire opal is yellow, orange or red in colour. Opal matrix consists of opal in its matrix. Besides the above some common opals have no play of colours; milk opal, resin opal, agate opal, rose opal, hyalite, etc.

*Occurrence.*—Most of the opal is the result of the decomposition of silicate minerals and volcanic glass by hot waters, and the silica thus dissolved is deposited in cracks and crevices. It is found to be widely distributed, but precious opal is found in only a few places. Opal was obtained from Czechoslovakia. Precious opal of good quality is also obtained from Australia, New South Wales and Queensland. Fire opal comes from Mexico and good opal from Latah country, Idaho.

In India opal is found in a number of places, e.g. Ahmednagar in Bombay, Nagpur in C.P., in Hyderabad near the city with chalcedony, carnelian and amethyst; in the Vizagapatam district in Madras replacing feldspathic portions of kodurite; and in Ajmer at the base of the hills near Srinagar.

## CHAPTER XXII

### NEPHRITE OR JADE

#### INTRODUCTION

JADEITE has been known to man since very early times. It is a semi-precious stone of great beauty and very much prized by the Chinese, who consider it a sacred stone

possessing certain magical properties. It is placed above all the other precious stones in China, and is carved into elaborate figures and designs. The Chinese believe that jade embodies the five cardinal virtues of charity, modesty, courage, justice and wisdom and the wearer gets immunity from accident and misfortune. Most of it went to China, but a demand has grown up in western countries as its wonderful colour and decorative value began to be appreciated. There is not much demand for jade in India. The stone takes a very good polish, and the polished surface has an oily lustre.

The term jade includes two minerals of similar appearance: (1) nephrite, and (2) jade. Nephrite is the more common form of jade. It is a monoclinic amphibole, compact, tough and the fracture is splintery. Hardness = 6 to  $6\frac{1}{2}$ . Specific gravity = 2.9 to 3.1. Colour: white to leaf green and grass green due to ferrous iron. It is translucent to opaque; pleochroic, mean refractive index = 1.62. Composition:  $\text{Ca}(\text{MgFe})_3(\text{SiO}_3)_4$ . Jadeite belongs to the pyroxene group and is rarer than nephrite, tough, compact and splintery. Hardness =  $6\frac{1}{2}$  to 7. Specific gravity = 3.3. Colour: White, greenish white or emerald green. Lustre: Subvitreous to pearly. Mean refractive index = 1.66. Composition:  $\text{NaAl}(\text{SiO}_3)_2$ . It fuses more readily than nephrite. Jadeite has a granular structure, whereas nephrite is a matted aggregate of fibres.

#### USES

Jadeite is used for making buttons, bars and brooches, small pieces for making bracelets, and beads for necklaces and bangles. Jadeite is also very much used for carvings in China.

#### GRADES

1. *Mya Yay* or *Yay kegauk*.—This is the most precious variety, and is translucent with a uniform grass-green colour.

2. *Shwelu* is a light green jadeite, with spots and streaks and is next to Mya Yay. These two varieties are used for cutting jewellery, e.g. rings, necklaces, pendants, etc.

3. *Lat-Yay* is clouded jadeite and is used for making bracelets, buttons, hatpins, ornaments, drinking cups, etc.

4. *Hmaw sit sit*—a dark green and soft variety, used in making cheaper jewellery.

5. *Konpi*—the red or brownish variety which is not found at Tawmaw.

6. *Kyauk atha*—white and translucent jadeite, used in making bracelets, stems of pipes, plates, spoons, etc.

7. *Pantha*—white and translucent, but opaque to some extent, which is considered a defect. It is used purely for decorative purposes.

8. *Kyauk-ame*—the black variety, used for making buttons, bars and brooches.

#### OCCURRENCE

Nephrite has been found in China, Turkestan, Siberia, New Zealand and Alaska. Jade is found in Upper Burma, Yunnan, Tibet, Mexico and South America.

Upper Burma is the only source of commercial supply of jadeite. It is obtained from the Uru valley in the Myitkyina district. The Uru chaung is an important stream, whose banks and small feeders are the sites of jadeite mining. Tawmaw, one of the chief mining centres, is situated about 68 miles by road from Mogaung railway station, which lies on the Sagaing-Myitkyina branch of the Burma Railways. It occurs in dykes of a metamorphic rock in a country rock of serpentine. The chief dyke is found at Tawmaw. Material is also available in a boulder conglomerate of Tertiary age and from pebbles from the Uru river. The quarries have been worked for centuries.

The biggest output of jadeite is at Tawmaw, which was discovered about 54 years ago. The length and breadth

of the proved outcrop are 300 and 200 yards respectively. The intrusion is considered to be a dyke, but it is also probable that the injection was in the form of a sill. The strike is N.E.—S.W., and swings round to N.N.E.—S.S.W. and E.N.E.—W.S.W. The well-known mines at Tawmaw are the Dwingyi and the Kadondwin. Besides Tawmaw dyke, there are also a few other dykes of jadeite rock. Jadeite also occurs as detrital boulders in Tertiary conglomerates.

### MINING

There are different kinds of mines: outcrop mines of (1) Dwingyi and (2) Kadondwin. The Dwingyi is the more important and consists of shafts and tunnels driven along the dyke, and few other old workings are also present. The jadeite was almost found at the surface with only 3 to 4 ft. of overburden. Serpentine was practically absent. Jade mining is done only for about three months a year from March to May, and the advent of the monsoon puts a stop to all activity. After the rains, the water has to be pumped out, which continues till the end of February. In addition to the indigenous bamboo pumps, steam pumps are also used nowadays. Then the mud, debris, etc., are removed and regular mining is started. In the Dwingyi mine, compressed air drills are used. Work is also carried on with blunt chisels, wedges and hammers. The tools soon get blunt as jadeite is tough and hard. The jadeite is also cracked by burning charcoal. The Kadondwin is worked on more modern lines. (For fuller details see Chhibber's *Mineral Resources of Burma*, pp. 46-47.) The mining industry at Tawmaw is gradually declining on account of the increasing depth of the mines.

### INDIGENOUS METHODS OF WORKING

When jadeite occurs in detrital deposits, surface workings are also done in the Tertiary conglomerates. Some of the

jadeite boulders found here are said to be about the size of a buffalo, which shows that the boulders have not travelled far from their source. The workings are usually on the hill-sides and river bed.

Before mining is started, 'jade-nats' (spirits) are propitiated by almost every worker, irrespective of his nationality. They believe that if the nats are pleased, the miners will have valuable finds quickly. Tools such as crowbars and spades are used and four men work together. Bamboo pumps are used for bailing water. In stream beds, as in the Uru river, mining is possible throughout the year. The water is dammed in the stream. After removal of the overburden, work is started in the boulders. Work is mostly of the primitive fashion. Just as in the Ruby Mines areas, if a valuable find is made on one spot all the miners rush to that spot and feverish mining starts there. The miners consist mostly of Kachins, Shans, Burmans, Chinese and occasionally Indians. The labour is financed by the jade merchants.

#### JADE-CUTTING INDUSTRY

Jade-cutting is really a Chinese industry, and artistic carving is mostly done in China. Surface carving and bead making are done at Mandalay.

The abrasives used are coarse carborundum and crushed gem from Mogok. The gem is crushed locally by girls. The powder obtained is mixed up with a gum imported from China. These abrasive slabs are mounted on flat rectangular plates. The first stage in the cutting of jadeite consists of sawing of boulders with big, heavy bamboo bows. The cutting is done with steel wire; generally two or three wires are used. Coarse carborundum and water are also used in the form of a paste, which is poured on the boulder continuously.

Small pieces are cut by means of a sharp-edged disc of bronze 14 inches in diameter. Fine carborundum and

water are supplied on the jadeite pieces, that are being cut. Then comes the shaping and polishing. The jade pieces are mounted on bamboo sticks by means of sealing wax, and are ground with great skill in abrasive tablets of different grades. The cut pieces are polished on slabs of very fine textured stones, brass, leather, etc. Final polishing is done on dry bamboo with water, and finally boiled for 15 minutes in a solution of soda, lime and water. After this treatment, it is cleaned with cloth and is ready for sale. The boring of holes for bangles and making of jade bangles demand great skill and is mostly done in China. A little work is done at Mandalay as well. The carving on jade also requires great skill and care. Jade cutting and carving form a great industry in China, the important centres being Canton, Shanghai and Peking as also Teng Yueh in Yunnan.

#### JADEITE TRADE

Jadeite is valued at the mines, and the owner has to pay a commission of 5% to the valuation committee in the jade mines, though the valuation in the mines is kept too low. If the stone is valued at Rs.100 or more, the owner has to pay the coolies half the value of the stone after paying 10% to the Diwa in whose jurisdiction the stone is found. In sales and valuation, prices are not mentioned openly, but a conventional system of finger pressure under a cloth is followed as is the case in the Ruby Mines area. The stone is taken to Mogaung where 33% of the value has to be paid to the government licensee. But there is a lot of underhand dealing in all these transactions.

Boulders of jadeite are shipped from Rangoon to Hong Kong, Canton, etc. There is also extensive smuggling across the border besides the normal trade. About 25% of the jadeite is consumed in Burma, and the remaining 75% in China and Japan, whence a small quantity goes to Europe and America. The Chinese



government buys a large quantity for making altars, sacred vessels, etc. The Chinese merchants usually purchase their jade at Mogaung, Hpaka, Hweka and other mining centres. Mandalay is the centre for cutting jade in Burma and commands the largest market for its jewellery.

#### FUTURE TREND

The market for jade depends largely on the Chinese market, and thus depends on the conditions in China.

### CHAPTER XXIII

## TURQUOIS

#### INTRODUCTION

TURQUOIS is supposed to have derived its name since it was exported from Turkey through Persia. The mineral is also found in Turkestan. It has a distinctive blue colour, which forms an agreeable contrast in a gold setting. It is apparently amorphous, but has been found to be triclinic recently. The Virginian turquoise has been found to be crystalline as very small crystals. Fracture conchoidal. Hardness = 6. Specific gravity = 2.6 to 2.8. Usually opaque with a waxy lustre. Colour varies from greenish grey, yellowish green, apple green to greenish blue and sky blue. The blue colour is due to copper and the green due to iron. Sky blue turquoise is most valued. On account of its porosity, it becomes dirty very easily. Refractive index = 1.63. It has a complex composition of a basic phosphate of copper and aluminium. Ferric iron may replace part of the aluminium.

#### USES

It is valued in jewellery due to its blue colour forming an agreeable contrast to the gold setting.

## VARIETIES, GRADES

(1) Turquoise matrix consists of bits of turquoise in a limonite matrix.

(2) Odontolite—it is not real turquoise, but is bone fossil turquoise. It is coloured blue either artificially or naturally distinguished by its organic structure.

## OCCURRENCES

It is formed from solutions, its associate being limonite, quartz, felspar, etc. Good turquoise comes from Persia and Egypt. In India it is found in the Ajmer hills and at Ramgarh, Rajputana.

Variscolite is another hydrated aluminium phosphate of an apple-green colour which is caused by the presence of chromium and vanadium. It is used at times in place of turquoise.

## CHAPTER XXIV

### LAPIS LAZULI (LAZURITE)

#### INTRODUCTION

LAZURITE has been known from very ancient times, as it was used for mosaics, inlaid work, etc., and was also used for the pigment ultramarine. It is a mixture of a number of minerals, of which lazurite is the most important, as it imparts the blue colour. Other minerals present are haüyne, diopside, amphibole, calcite and pyrite. Hardness =  $5\frac{1}{2}$ . Specific gravity varies from 2.5 to 2.95. Sp. gr. of the pure mineral is 2.4. Colour varies from deep blue to azure blue, etc. Lustre: Vitreous to greasy. Opaque to transparent. Cubic. Refractive index = 1.50. It has a complex chemical composition. It is a complex aluminosilicate and sulphide of sodium accompanied by HCl.

## USES

It has been used for ornamental purposes, for mosaics, vases, inlaid work and other ornamental objects. When used for jewellery it is cut en cabochon. Formerly it was also used for the pigment, 'ultramarine'. The paint is now made artificially.

## OCCURRENCE

The best quality of lapis lazuli comes from Badakshan in the N.E. corner of Afghanistan, where ruby spinels also occur. It is also obtained from Siberia, Chile and California. The rock has been produced by the baking of an impure limestone near its contact with an intruded mass of granite, when the contact has the right content of clay matter, sodium and sulphur. It is obtained at Badakshan, north-east corner of Afghanistan and the Mogok Stone Tract, Burma at Dattaw near Mogok, where ruby and spinel are also obtained.

## CHAPTER XXV

### OTHER SEMI-PRECIOUS STONES

#### INTRODUCTION

MOST of these are not found in India and are only of mineralogical interest:—

1. *Anatase*.—When brown and transparent it is cut for gem purposes. It is also known as octahedrite. Tetragonal. Hardness =  $5\frac{1}{2}$  to 6, specific gravity = 3.8 to 4.0. Colour: brown to black, adamantine lustre. Refractive index:  $\omega = 2.55$ ,  $\epsilon = 2.49$ , double refraction, strong—0.06. Uniaxial and optically negative. It occurs in Cornwall, England, France, Germany, Brazil, etc.

2. *Andalusite*.—Occurs in orthorhombic crystals. Hardness = 7 to  $7\frac{1}{2}$ . Specific gravity = 3.1 to 3.2. Colours vary from grey, green, pink, red and violet. Lustre: Vitreous to dull, transparent to opaque. Mean refractive index

= 1.64. Strongly pleochroic. At times the cut stones resemble tourmaline and apatite of similar colour. Chiastolite has carbonaceous inclusions, and when cut in sections shows a black cross. Composition  $\text{Al}_2\text{SiO}_5$ . It is cut in the step fashion. It is obtained from Spain, Ceylon and Brazil.

3. *Apatite*.—Apatite forms good hexagonal crystals and makes attractive gems. Hardness = 5 and soft. Specific gravity = 3.1 to 3.2. It is usually coloured by impurities and colour varies from green to pink, blue, purple or violet. Gem varieties are transparent. Mean refractive index = 1.64, double refraction = 0.004, uniaxial and negative. It is found in pegmatite, igneous and metamorphic rocks. Blue crystals are obtained from the Ruby Mines of Burma. A deep sea-green variety is obtained from Devada, Vizagapatam and from Kodur from the same district. A green apatite occurs in pegmatite in Ajmere in Rajputana. Apatite of gem quality also occurs in Germany, Switzerland and Ceylon.

4. *Azurite and malachite*.—These are coloured blue and green and find use in decoration and miscellaneous gems, as in pins, shirt buttons, etc. Monoclinic. Azurite is often crystallized, but malachite occurs in rounded masses with a fibrous or banded structure. Hardness =  $3\frac{1}{2}$ . Specific gravity = 3.7 to 4.0. Malachite—emerald green, grass-green; azurite—light blue to deep blue. Translucent to opaque. Lustre—silky, vitreous or adamantine; mean refractive index for malachite = 1.81 and for azurite = 1.77. Double refraction strong 0.26 for malachite and 0.11 for azurite. Both are biaxial. Azurite is optically positive and malachite negative. Composition: Azurite ( $2\text{CuCO}_3, \text{CuOH}$ ); malachite  $\text{CuCO}_3.\text{Cu}(\text{OH})_2$ . Occurrence: Urals, Rhodesia, Chile, Belgian Congo and Australia.

5. *Benitoite*.—It was discovered in 1907 in San Benito County, California, the only known locality. Due to its deep blue colour, it resembles sapphire, but differs by its

inferior hardness and optical properties. Hardness =  $6\frac{1}{2}$ . Specific gravity = 3.65. Lustre: Vitreous, dichroic, the table should be cut parallel to the vertical axis. Refractive index:  $\omega = 1.757$  and  $\epsilon = 1.804$ . Composition:  $\text{BaTiSi}_3\text{O}_9$ .

6. *Cassiterite*.—Transparent cassiterite is rare, but is sometimes used as a gem. Good crystals occur in Cornwall, England, Germany and Bolivia.

7. *Chloroastrolite*.—A greenish fibrous mineral with chatoyancy. Hardness = 5.6. Specific gravity = 3.2. The gem is cut cabochon and worn in pins, brooches, etc.

8. *Cyanite* occurs in bladed triclinic crystals. Hardness (varies with direction) = 4 to 7. Specific gravity = 3.5 to 3.7. The mineral is light to sky blue or white, grey, green, brown, etc. Colourless. Lustre: Vitreous, transparent to translucent. Refractive index = 1.72; and double refraction = 0.016. Composition:  $\text{Al}_2\text{SiO}_5$ . Clear cyanite with good colour may be cut for gems. It occurs in metamorphic rocks. Important localities: Switzerland, Tyrol, Brazil, etc.

9. *Diopside* of a pleasing green colour is sometimes obtained. Hardness = 5 to 6. Specific gravity = 3.2 to 3.3. Mean refractive index = 1.68; double refraction = 0.03. Biaxial and optically negative. It occurs in metamorphosed limestones as an associate of diamond in the mines of South Africa. Good crystals are obtained at Piedmont, Italy, the Tyrol, Ontario and New York.

10. *Enstatite*, *Bronzite* and *Hypersthene*.—These are isomorphous minerals with varying proportions of iron and magnesia. They are occasionally used for gem purposes. Bronzite has a chatoyant bronzy lustre and hypersthene has a metalloidal iridescent lustre, when cut cabochon. Orthorhombic pyroxenes—colour varies from greyish white, greenish, yellowish, etc. Hardness = 5 to 6. Specific gravity = 3.1 to 3.5. Mean refractive index = 1.66 to 1.70.

11.—*Euclase*. It is a beryllium mineral ( $\text{HBeAlSiO}_5$ ), which is obtained in the Urals and Brazil. It occurs as small monoclinic crystals with perfect cleavage in one direction.

Colour varies from sea-green to green or blue, resembling aquamarine. It occurs in metamorphic rocks. It is found in Kashmir with sapphires, also in Ural Mountains, and Minas Geraes, Brazil. Mean refractive index = 1.65 and double refraction = 0.02. Biaxial and optically negative.

12. *Felspar*.—It is an important rock forming mineral, most of it is opaque and valueless but some of it is of gem quality. Transparent and colourless varieties are known as adularia and moonstone—opalescent. Moonstone varieties of albite and adularia are also found. (a) Moonstones are cut cabochon and are obtained in the gem gravels of Ceylon and in Burma in pegmatite in the area east of Mogok. It is also locally cut at Mogok and sold as cheap precious stones. It is also obtained from Switzerland and Elba. (b) Amazon stone is a variety of microcline and has a pleasing colour like that of jade and is cut cabochon. It is used in brooches and pendants. It is obtained from Ural Mountains, Pennsylvania, Virginia and Colorado. It was also obtained two miles south of Domchanch, Hazaribagh district, Bihar and also in Kashmir, and from near Saidapuram, Nellore, Madras. (c) Sunstone or aventurine is oligoclase, recorded from Mogok by Prof. Judd. It is obtained in Norway and Siberia. (d) Labradorite—soda lime felspar—has a beautiful play of colours in blue and green and less often in yellow, red and grey. The mineral takes its name from Labrador and also occasionally found in the syenites of Mogok.

13. *Flourite or flourspar*.—It occurs in good cubic crystals—twinning seen as interpenetration cubes. Cleavage—octahedral, perfect. Hardness = 4. Specific gravity = 3.1 to 3.2. It has attractive colours and may be transparent to opaque. It has a vitreous lustre and is fluorescent and phosphorescent. Isotropic. Refractive index = 1.434. Composition:  $\text{CaF}_2$ . It is carved as vases, dishes, etc. The best material is obtained from Derbyshire, Cumberland,

Cornwall, Devonshire and Durham in England. In India it is found in Kishengarh State, Rajputana; Degana, Jodhpur State; Tavoy, Burma, and in small quantities in several other places.

14. *Gypsum*.—Satinspar is used in cheap jewellery, being a fibrous chatoyant variety with a silky lustre. It is cut cabochon as beads, found in England and Russia. Hardness = 2. Specific gravity = 2.2 to 2.4. It is usually colourless, white, grey, yellow, brown, etc. Mean refractive index = 1.525. Double refraction = 0.010. Composition:  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ .

15. *Iolite*.—It is also known as cordierite or dichroite, due to its pleochroism. Orthorhombic. It is a complex aluminosilicate of magnesium and iron. Colour: deep blue—not much used as a gem. Hardness = 7 to  $7\frac{1}{2}$ . Specific gravity = 2.6. Refractive index = 1.54 to 1.56. It is found in Ceylon and is known as 'water sapphire'. It has been found in Travancore, in Trichinopoly and Madras, and in gem gravels in Mogok, Burma.

16. *Phenacite*.—Good crystals are obtained from the emerald mines of the Urals. It has a little fire and is little used as a gem. Hexagonal. Hardness =  $7\frac{1}{2}$  to 8. Specific gravity = 3.0. Colourless, yellowish or pale rose-red, transparent to translucent. Mean refractive index = 1.66, and double refraction = 0.016. Composition:  $\text{Be}_2\text{SiO}_4$ . It is obtained in the Mogok Ruby Mines of Burma. It somewhat resembles diamond but is lacking in fire. It is also obtained in the Ural Mountains, Brazil, Mexico and Colorado.

17. *Prehnite*.—It is sometimes used as a gem, when it has an oily lustre and is found in rounded masses. Hardness = 6 to  $6\frac{1}{2}$ . Specific gravity = 2.80 to 3.0. Colourless, white, light-green, apple-green, etc. Transparent to translucent. It occurs in France, Lake Superior, etc.

18. *Rhodonite*.—It is a pink-red mineral, polishing well. It is used in Russia as an ornamental stone. It is

cut cabochon for use in pins, or beads or buttons. Triclinic and occurs in crystals or compact masses. Hardness = 5.5. Specific gravity = 3.4 to 3.7. Colour: rose-red or pink; also yellow, green or brown. Lustre: Vitreous to pearly. Mean refractive index = 1.73. Composition:  $\text{MnSiO}_3$ . It is found in many manganese mines in the Central Provinces, Central India, Bombay and Madras. It occurs in a massive form. Colour: brownish-red, flesh-red or rose-pink. It is also obtained from the Ural Mountains and from Franklin, New Jersey.

19. *Serpentine*.—It is a hydrated silicate of magnesia with iron. It is used for ornamental purposes and cut cabochon for gems. Monoclinic but never occurs in crystals and forms platy or fibrous masses. Hardness =  $2\frac{1}{2}$  to 4. Specific gravity = 2.5 to 2.8. Colour: various shades of green, also yellowish, greyish, reddish, brownish or black. Lustre: dull, resinous, greasy or waxy. Feel is smooth to greasy or waxy. Mean refractive index variable, 1.50 to 1.55. Precious serpentine is translucent and green or yellow in colour. Varieties:—Bowenite—granular and resembles jade; Williamsite—blackish green; Verde antique—massive green; Chrysotile—fibrous. Good material is found in Sweden, Scotland, Silesia, Saxony, Rhode Island, Vermont, Massachusetts, Pennsylvania and California. Some material of attractive colour is found in the asbestos mines near Pulivendla, Cuddapah district, Madras.

20. *Smithsonite*.—Though usually unattractive, those of yellow-green or blue may be cut cabochon or used for ornamentation. Composition— $\text{ZnCO}_3$ . It is formed by the alteration of zinc sulphide and occurs in limestone and dolomite.

21. *Sodalite* is polished as an ornamental stone or sometimes cut cabochon. It is deep blue in colour and resembles lazurite. Cubic. Isotropic. Hardness = 5 to 6. Specific gravity = 2.24. It is found in the Ural Mountains



and other areas. A good locality in India is in the Kishengarh State, Rajputana.

22. *Spodumene*.—It is a silicate of lithium and aluminium and forms greenish-grey crystals. Two varieties are used as gems: (i) Hiddenite—yellow-green to emerald green, and (ii) Kunzite—delicate pink to lilac in colour. Both are transparent. Monoclinic and it occurs in large crystals and tabular masses. Cleavage: prismatic and parting pinacoidal. Hardness = 6 to 7. Specific gravity = 3.1 to 3.2. Colour: white, grey, green or purple. Lustre is vitreous to pearly. Transparent to opaque. Mean refractive index = 1.67. Double refraction = 0.016. Coloured varieties are pleochroic; kunzite is phosphorescent. The kunzite variety is obtained near Pala, California and Madagascar. The spotted and transparent variety comes from Brazil.

23. *Staurolite*.—Orthorhombic, and is a complex aluminosilicate of iron and magnesium. It forms cross-shaped twins and is often worn as charms, and is used by the clergy due to cross-shaped twins. Hardness = 7 to  $7\frac{1}{2}$ . Specific gravity = 3.4 to 3.8. Colour: reddish-brown. Translucent to opaque. Pleochroic. Mean refractive index = 1.74. Good crystals come from St. Gothard, Switzerland, from the Tyrol, in Brazil and Virginia.

24. *Sphene* makes an attractive gem, but is rather soft. Colour: yellow, green or brown. Lustre: adamantine, transparent to opaque. Refractive index is very high,  $\alpha = 1.90$ ,  $\gamma = 2.30$ . Composition:  $\text{CaTiSiO}_5$ . Good crystals occur in schists or limestone in Switzerland, Tyrol and many other localities; also in Madagascar, Maine, New York and Pennsylvania.

25. *Idocrase (Vesuvianite)*.—It resembles jade, cyprine is a blue variety. Tetragonal. Hardness =  $6\frac{1}{2}$ . Specific gravity = 3.3 to 3.5. Colour varies from yellow, green, brown, blue, red, etc. It is translucent with a glassy lustre, etc. Mean refractive index = 1.72. It is found

from Mount Vesuvius, Siberia, Germany, Norway and California.

26. *Zoisite* belongs to the epidote group, orthorhombic. Colour : grey, greenish or red. The manganese variety is known as *thulite*, and is used for ornamental objects or cut cabochon. It occurs in Norway and in Piedmont, Italy.

## CHAPTER XXVI

### GEM MATERIALS OF ORGANIC ORIGIN

#### PEARLS

PEARLS, though an animal product, are held in great esteem by jewellers and lovers of gems in all parts of the world. They were known to the ancients, and held the highest place among gems, since the beauty of the pearl is entirely due to nature. The Hindus ascribed its origin to God Vishnu. Pearls were also held in great esteem by the Persians, and were known even in 2300 B.C. In ancient times, pearls were also paid as tributes. Pearls were also considered as emblems of purity, beauty and nobility and also to have possessed medicinal effects.

Pearls are found in the shells of oysters and mussels. These animals withdraw calcium carbonate from the sea-water and use it for building their shells, which are composed of organic material conchiolin and calcium carbonate in its two crystalline forms calcite and aragonite. The outside of the shell is conchiolin and the inner portion is composed of two layers—the outer of these consist of calcite and conchiolin and the inner of aragonite and conchiolin. The inner layer furnishes mother of pearl, etc.

*Origin of pearl.*—When a grain of sand or any other foreign object enters the shell of a mollusc, irritation is caused, which results in the secretion about the offending particle or parasite, layer by layer and then the pearl is built up. The knowledge of this phenomenon by man has

been used to produce artificial or cultured pearls. A small object is placed inside the oyster and then it is returned to water. After a year or two the oyster is withdrawn and the pearl removed. In Japan by a particular process the oysters are caused to grow pearls of a spherical shape, very much resembling natural pearls. In the natural pearls, growth is concentric whereas in the artificial growth is seen to be parallel and only concentric layers are seen on the outer surface. Pearls are composed largely of aragonite ( $\text{CaCO}_3$ ), with some conchiolin. Hardness =  $2\frac{1}{2}$  to  $3\frac{1}{2}$ . Specific gravity = 2.5 to 2.7. It is most often white, faint yellow, bluish and even red, green and black. Translucent to opaque. Lustre: Pearly also iridescent.

The best pearls have a spherical form, lustrous and iridescent, free from blemishes and somewhat transparent. White ones are priced most. Pearls of irregular shape are known as 'Baroque'. Flat pearls are known as button pearls. Due to softness, it is easily scratched. The lustre is affected by heat, acids or foetid gases. Age also causes deterioration, and the lustre once lost cannot be restored.

Pearl fisheries are operated along the Indian coasts, near Mannar between India and Ceylon, the Persian Gulf, the Red Sea, Japan, Antarctic, etc., also in rivers in Europe, America, China and Japan; so that there are marine and fresh-water fisheries of oysters.

*Boring and polishing.* These have to be done very carefully and done by the help of pearl dust. After wearing on the body they are liable to lose lustre. They have to be wiped by clean linen or silk and kept covered in a closed box.

Imitation pearls consist of hollow spheres of thin glass coated with a preparation from fish scales and filled with white wax. A translucent white glass with a pearly lustre may also be used to imitate the gem.

*Price of pearls.*—Price depends on their form, texture, transparency and lustre. Spherical pearls fetch the highest price and those with fancy colours sell at any price. Large

pearls are sold by the carat. There have also been celebrated pearls in the possession of Royalty and Nobility and most of the Indian Princes and nobles have also a good collection of pearls, especially necklaces.

## CORALS

*Introduction.*—The coral was known to the ancients and the Greek tradition was that it sprung out of the blood dropping from the head of Medusa, which was deposited near the shore by Perseus, and was taken away by the sea-nymphs and planted in the sea. It is not so much liked in Europe as it was in former times. It is in great demand in certain parts of India. India used to spend Rs.20 lakhs per annum on corals. It is held in great esteem by the Eastern nations. The red coral was once considered the most valuable, but present fashion favours the pink ones.

The coral is often imitated by bone, horn and ivory stained with cinnabar. The coral was also held in great esteem in most ancient times, and was supposed to be marvellous and to have medicinal powers. It was used both as a medicine and a charm.

The coral, like the pearl is composed of calcium carbonate, and is secreted by small sea-animals known as coral polyps for building their skeleton. The red coral is considered precious. Colour varies from red to pink. Hardness = 3.5. Specific gravity = 2.6 to 2.7. The red coral is dredged from waters of moderate depth along the Mediterranean shores; as for instance, along the African coast 700–800 ft. below the surface of the sea. The coral fishery is carried out by Italians, Maltese and French, and divers are also utilized. Black coral has been obtained from the Persian Gulf and the Great Barrier Reef of Australia. Coral is used for necklaces, bracelets, etc.

*Cutting and boring of coral beads, etc.*—Pieces are cut en cabochon into drops for earrings and also into leaves, flowers and various other forms. It is bored by steel

needles, by hand and machinery. The working of coral is carried on in Marseilles, Leghorn and Genoa. The coral is exported to India, Persia, China and Japan. Coral may also be used for cameo.

### AMBER

Amber is an inorganic product or fossil resin, occurring in the form of pebbles or irregular shaped masses in beds of Tertiary age. The life of its period could be studied by the insects entombed in the amber. The amber was first in a sticky state, when the insects were entrapped in it. It was exuded by an extinct genus of pine tree, known as *Pinus succinifera*. Most of the world's amber comes from the deposits along the southern shores of the Baltic Sea, West and North of Königsberg, Germany. But amber occurs also in Rumania, Sicily and Burma.

Baltic amber occurs in grains and lumps weighing even up to 20 lbs. It contains inclusions of a great variety of insects and plant remains, which are well preserved and are objects of scientific and popular interest. Minute inclusions of pyrite may also be present. Hardness = 2 to  $2\frac{1}{2}$ . Amorphous. Fracture: conchoidal, and takes a good polish. Specific gravity 1.0 to 1.1. It floats in a glass of water containing four heaped tea-spoonfuls of salt. Colour: yellow, but other colours as brown, white, red, etc. may also be present. Lustre: greasy. Clear and transparent or cloudy to translucent and opaque. Amorphous, isotropic. Refractive index = 1.54. It is easily electrified by rubbing with a cloth and will attract bits of paper. It is warm to the touch being a very poor conductor of heat. It is a good insulator and is used in electric and radio apparatus.

*Composition.*—It is a mixture of several resins, succinic acid and a volatile oil called amber oil with also a little  $H_2S$ .

*Occurrence.*—The Baltic Sea coast exposure is the most important. Palmnicken is the centre of mining operations. The manufacturing works for amber articles are at

Konigsberg. The amber bed is also exposed on the coast and is worked on the shore by the sea. In Burma it is known as Burmite and is harder than succinite. The chief area is the Hukong valley. It is pale yellow in colour, but red and black varieties are also common. Burmite is valued in Burma, India and China, but still there is some import of the Baltic amber.

Imitations of coral and bakelite are also common. Specific gravity is one test. Bakelite has 1.25 to 1.28. It will sink in the salt water solution mentioned already, whereas amber will float.

### JET

It is a hard and compact variety of lignite, often used for cheap jewellery and beads. Hardness = 2 to 2.5, and specific gravity = 1.1 to 1.4. Black bakelite can be made to imitate the same.

# TABLE OF HARDNESS, SPECIFIC GRAVITY, REFRACTIVE INDEX, ETC.

<i>Name of Mineral.</i>	<i>Hardness.</i>	<i>Sp. gravity.</i>	<i>Refractive index</i> <i>n = Mean R.I.</i>	<i>D. Ref. w-e,</i> <i>or <math>\omega - \epsilon</math>, <math>\gamma - \alpha</math></i>
Amber	.. 2-2½	1.0-1.11	1.54	
Anatase	.. 5½-6	3.8-4.0	$\omega = 2.55$ , $\epsilon = 2.49$	0.06
Andalusite	.. 7-7½	3.1-3.2	$n = 1.64$	0.01
Apatite	.. 5	3.1-3.2	1.64	0.04
Axinite	.. 6½	3.3	1.68	0.009
Azurite	.. 3½	3.7-3.8	1.71	0.011
Benitoite	.. 6½	3.3	$\omega = 1.76$ , $\epsilon = 1.80$	0.047
Beryl	.. 7½-8	2.6-2.8	1.58	0.006
Beryllonite	.. 5½-6	2.85	1.56	0.001
Cassiterite	.. 6-7	6.8-7.0	2.04	0.10
Chlorastrolite.	.. 5-6	3.2	..	..
Chromite	.. 5½	4.3-4.6	..	..
Chrysoberyl	.. 8½	3.5-3.8	1.75	0.010
Chrysocolla	.. 2-4	2.0-2.2	1.50	0.11
Cobaltite	.. 5½	6.0-6.4	..	..
Coral	.. 3½	2.6-2.7	..	..
Corundum	.. 9	3.9-4.1	1.76	0.008
Cyanite	.. 4-7, varying with direc- tion.	3.5-3.7	1.72	0.012
Datolite	.. 5-5½	2.9-3.0	1.63	0.04
Diamond	.. 10	3.5	2.42	Dispersion 0.058
Diopside	.. 5-6	3.2-3.3	1.68	0.03
Enstatite	.. 5-6	3.1-3.5	1.67-1.70	0.01
Epidote	.. 6-7	3.3-3.5	1.75	0.04
Euclase	.. 7½	3.1	1.65	0.02
Felspar	.. 6-6½	2.5-2.8	1.52-1.58	0.005-0.012
Fluorite	.. 4	3.0-3.2	1.434	..
Garnet	.. 6½-7½	3.4-4.3	1.70-1.90	..
Grossularite	.. ..	3.4-3.7	1.735	..
Pyrope	.. ..	3.7-3.8	1.705	Dispersion 0.024-0.028
Almandine	.. ..	3.9-4.20	1.830	
Andradite	.. ..	3.8-3.9	1.895	0.057 for dementioid
Gold	.. 2½-3	19-19.3	..	..
Gypsum	.. 2	2.2-2.4	1.525	0.010

Name of mineral. Hardness.		Sp. gravity.	Refractive index	D. Ref. $w-e$ , $n = \text{Mean R.I. or } \omega-e, \gamma-\alpha$
Hematite	.. $5\frac{1}{2}-6\frac{1}{2}$	4.9-5.3	..	..
Iolite	.. $7-7\frac{1}{2}$	2.6	1.55	0.008
Jade	.. $6\frac{1}{2}-7$	3.1	1.6 nephrite	..
			1.67 jade	..
Jet	.. $2-2\frac{1}{2}$	1.1-1.4	..	..
Lazulite	.. $5-6\frac{1}{2}$	3.1	1.62	0.036
Lazurite	.. $5-5\frac{1}{2}$	2.4	1.50	..
Malachite	.. $3\frac{1}{2}$	3.7-4.0	1.81	0.26
Olivine	.. $6\frac{1}{2}-7$	3.2-3.6	1.68	0.04
Opal	.. $5\frac{1}{2}-6\frac{1}{2}$	2.1-2.3	1.44-1.45	..
Pearl	.. $2\frac{1}{2}-3\frac{1}{2}$	2.5-2.7	..	..
Phenacite	.. $7\frac{1}{2}-8$	3.0	1.66	0.016
Prehnite	.. $6-7$	2.8-3.0	1.63	0.03
Quartz	.. $7$	2.7	1.55	0.009
				0.013
Rhodonite	.. $5-6$	3.4-3.7	1.73	0.01
Rutile	.. $6-6\frac{1}{2}$	4.2-4.3	$\omega = 2.62$	0.28
			$e = 2.90$	
Sepiolite	.. $2-2\frac{1}{2}$	1.2	1.55	..
Serpentine	.. $2\frac{1}{2}-4$	2.5-2.8	1.53	..
Smithsonite	.. $5$	4.1-4.5	1.75	0.20
Sodalite	.. $5-6$	2.2-2.4	1.48	..
Spinel	.. $8$	3.1-3.2	1.72	..
Spodumene	.. $6-7$	3.1-3.2	1.66	0.026
Staurolite	.. $7-7\frac{1}{2}$	3.4-3.8	1.74	0.010
Thomsonite	.. $5-5\frac{1}{2}$	2.3-2.4	1.51	0.03
Titanite	.. $5-5\frac{1}{2}$	3.4-3.6	$\alpha = 1.90$	0.13
			$\gamma = 2.03$	..
Topaz	.. $8$	3.4-3.6	1.62-1.63	0.010
Tourmaline	.. $7-7\frac{1}{2}$	2.9-3.2	1.63	0.020
Turquoise	.. $6$	2.6-2.8	1.63	..
Veriscite	.. $4-5$	2.5	..	..
Vesuvianite	.. $6\frac{1}{2}$	3.3-3.5	1.72	0.006
Zircon	.. $7\frac{1}{2}$	4.0-4.8	$\omega = 1.92$	0.05
			$e = 1.95$	..
Zoisite	.. $6-6\frac{1}{2}$	3.3-3.4	1.70	0.006



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